EXPOSURE AND RISK ASSESSMENT FOR ARSENIC IN SİMAV PLAIN BY INGESTION OF EDIBLE CROPS

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ABSTRACT

EXPOSURE AND RISK ASSESSMENT FOR ARSENIC IN SİMAV PLAIN BY INGESTION OF EDIBLE CROPS

Ingestion is the main route of exposure to arsenic. The pathways of concern are ingestion of drinking water and arsenic-accumulating plants. Simav plain has been shown to have the natural arsenic conamination of waters and soil. However, foodstuff was not made a subject of investigation. In this study, arsenic exposure via ingestion of edible plants cultivated in Simav plain was investigated based on the modeling of the measured soil concentrations and data collected from the literature, which were for bioconcentration factors, plant consumption rates, background arsenic concentrations in plants, plant root depths, and body weights. Eighteen plant species, which are bean, broccoli, cabbage, carrot, cauliflower, corn, cucumber, eggplant, garlic, lettuce, okra, onion, potato, radish, spinach, sunflower seed, tomato, and wheat were studied. Chronic-toxic and carcinogenic risks associated with the consumption contaminated foodstuff were assessed with two approaches: scenario based point estimates (deterministic approach) and population based estimates (probabilistic approach). Monte Carlo simulation was used to determine chronic-toxic and carcinogenic risks via ingestion of edible plants probabilistically. Wheat was found as the plant variety with the highest non-carcinogenic and carcinogenic risks which was followed by potato, tomato, cucumber, corn, cabbage, eggplant, and onion. Non-carcinogenic risk levels for broccoli, cauliflower, garlic, and radish were below the threshold level. However, their carcinogenic risk levels were considerable. The risk levels estimated in this study are exceptionally high, indicating consumption of the plants cultivated in Simav may pose significant chronic-toxic and carcinogenic health risks.

ÖZET

SİMAV OVASINDA YETİŞEN YENİLEBİLİR BİTKİLER İÇİN ARSENİK MARUZİYETİ VE RİSK DEĞERLENDİRMESİ

Sindirim ile maruziyet, arseniğe maruz kalmanın temel yoludur. Arsenik ile kontamine olmuş bitkiler ve içme suları, sindirim yoluyla arsenik maruziyetinin temel taşlarıdır. Simav ovasında, topraktaki ve sudaki yüksek arsenik konsantrasyonlarını gösteren çalışmalar bulunmaktadır. Ancak, Simav ovasında yetişen bitkilerdeki arsenik konsantrasyonları hakkında yapılmış bir çalışma bulunmamaktadır. Bu çalışmada, Simav ovasında yetişen yenilebilen bitkiler için sindirim yoluyla maruziyet araştırılmıştır. Bu kapsamda, literatürden toplanan biyokonsantrasyon faktörleri, bitki tüketim oranları, bitkilerdeki doğal arsenik konsantrasyonları, Simav ovası toprağındaki arsenik konsantrasyonları, bitki kök derinlikleri ve Türk halkı için kilo verileri ile modelleme yapılmıştır. On sekiz yenilebilen bitki türü (fasulye, brokoli, lahana, havuç, karnabahar, mısır, hıyar, patlıcan, sarımsak, marul, bamya, soğan, patates, turp, ıspanak, ayçekirdeği, domates ve buğday) çalışma kapsamındadır. Arsenik ile kontamine olmuş yiyecek maddeleri için kronik-toksik ve kanserojenik riskler senaryo bazlı noktasal tahminler (deterministik yaklaşım) ve popülasyon bazlı tahminler (olasılıksal yaklaşım) olmak üzere iki farklı yöntemle değerlendirilmiştir. Olasılıksal yaklaşımda, kanserojenik ve kronik-toksik risklerin hesaplanması için Monte-Carlo simülasyonu kullanılmıştır. Olasılıksal yaklaşım sonunda, buğday hem kronik-toksik hem de kanserojenik risk ile en ilintili tür olarak bulunmuştur. Buğdayı patates, domates, soğan, hıyar, lahana, mısır ve patlıcan takip etmektedir. Brokoli, sarımsak, turp ve bamyanın kronik-toksik risk değerleri limit değerin altında kalmıştır ancak kanserojenik riskleri önemli ölçüdedir. Bu çalışmada bulunan olağandışı risk değerleri Simav ovasında yetişen bitkilerin insan sağlığına kronik-toksik ve kanserojenik etkileri olabileceğini göstermiştir.

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CHAPTER 1

INTRODUCTION

For centuries, soil has been very important for the humankind. Its productivity has been the source of nutrition and life. Soil interacts with the lithosphere, the hydrosphere, the atmosphere, and the biosphere. Owing to these interactions it is prone to contamination and pollution. Protecting soil from pollution is essential for maintenance of its productivity and agricultural functions.

Arsenic is a poisonous trace element found naturally in the Earth's crust. The average background concentration of arsenic in surface soils of world is 6.83 mg/kg (Kabata-Pendias and Pendias, 2011, p.41). In recent years, relation between soil and plants has gained attention due to increasing arsenic pollution. Especially, transfer of arsenic to edible plants is a substantial issue because it is one of the major exposure pathways, therefore concerns human health. The US Environmental Protection Agency (US EPA), classified arsenic as a human carcinogen and emphasizes that arsenic causes bladder, lung, kidney, and liver cancers (US EPA, 1988). The Joint Food and Agriculture Organization of the United Nations/WHO Expert Committee on Food Additives (JECFA) has replaced the tolerable intake for inorganic arsenic with a benchmark dose lower confidence limit for a 0.5% increased incidence of human lung cancer ($BMDL_{0.5}$) in 2010 (JEFCA, 2010).

Arsenic contamination of agronomic crops may result from anthropogenic or natural sources. Application of wrong agricultural practices such as arsenic containing fertilizers and pesticides may cause pollution in agronomic areas thus in agronomic crops (Bissen and Frimmel, 2003). Some agricultural areas, however, have naturally high arsenic levels due to parental rocks of soil or contaminated groundwater thus may pollute agronomic crops. Arsenic can leach out of rocks and solved in water. Arsenic transport from rocks to water is higher from geothermal waters under the effect of temperature. Şimşek (2005) have found that arsenic contamination in geothermal waters of Balçova is quite high (1420 µg/L) affecting the irrigation water quality. Dahal et al. (2008) reported that arsenic in potato was correlated both with soil (99%) and irrigation water (95%), while other species (rice, cauliflower, oninon, and eggplant) were more linked with arsenic in irrigation water.

Kütahya is a province of Turkey which have naturally high levels of arsenic in its groundwaters and soils. Emet and Simav are the districts of Kütahya where arsenic pollution is observed. Ünlü et al. (2011) reported the range of arsenic concentrations in water of Emet city as 100 µg/l – 450 µg/l which is at least 10 times the recommended limit by World Health Organization (WHO 2010). Soil arsenic concentrations measured by Özkul et al. (2011) varied between 0.40 and 2488 mg/kg. Range of maximum allowable concentrations of arsenic in agricultural areas differs among countries: 2 to 50 mg/kg (Kabata-pendias and Pendias 2001).

Gündüz et al. (2010) studied arsenic pollution in the waters of Simav plain and found that arsenic concentrations in surface water samples were between 60 and 179 µg/l which is at least six times the arsenic concentration limit recommended by WHO (2010). For the groundwater samples, arsenic concentrations were found relatively higher than the surface water samples and ranged between 0.5 and 562 µg/l. Soil arsenic concentrations in the Simav plain varied between 18 to 113 mg/kg (Gündüz et al., 2012). These high arsenic levels in soils and waters warrant the hypothesis that crops grown on Simav plain are most probably contaminated with arsenic and may be a major exposure pathway.

The goals of this study are (1) to estimate the concentrations of arsenic in the crops cultivated in Simav, (2) estimate exposure and (3) health risk levels associated with their consumption for Simav population. In the following chapters, information related to arsenic transport from soil to plants and crop arsenic concentrations (Chapter 2), human health risk assessment and the studies about arsenic exposure via ingestion of crops (Chapter 3), material and methods used in this study (Chapter 4), results and discussion (Chapter 5) and conclusions (Chapter 6) are presented.

CHAPTER 2

LITERATURE REVIEW

2.1. Arsenic and Soil

Arsenic is a non-essential trace element which mostly presents in soils in four oxidation states: arsenate, arsenite, arsenic and arsine (Bissen and Frimmel, 2003). Generally, arsenate (As^{V}) and arsenite (As^{III}) are the superior species that found in soils (Farooq et al., 2016). Arsenate is the dominant arsenic variety that found in aerobic soils while arsenite is commonly superior in the anaerobic or flooded soils (Bissen and Frimmel, 2003; Yoon et al., 2015). Zhang and Selim (2008) emphasize that arsenate and arsenite are environmentally significant because of their solubility in water which increases bioavailability of arsenic to plants. However, arsenic speciation in soil may differ depending on the soil features. Abiotic and biotic factors affect arsenic speciation in soil thus arsenic mobility and bioavailability.

Arsenic mobility in soils hinges on the adsorbing soil constituents (Bissen and Frimmel, 2003). Chemical and microbiological reactions play an important role on biogeochemistry of arsenic. Zhang and Selim (2008) state these reactions as reduction-oxidation, dissolution-precipitation, acid-base reactions and biomethylation. Among the properties of soil, pH and Eh value, cation exchange capacity, organic matter, oxides and hydroxides, temperature and residence time, soil constituents, and microorganisms are the most important factors which affect arsenic mobilization and immobilization in soil (Kabata-Pendias and Pendias, 2011; Zhang and Selim, 2008).

2.1.1. pH and Eh Effects on Arsenic

Soil pH governs two main factors; mineral surface potential and arsenic speciation which implicitly affects arsenic adsorption onto mineral surfaces (Zhang and Selim 2008, p.56). Arsenate is the dominant arsenic variety when the sum of pH and pe bigger than 10 while arsenite is dominant when the sum of pH and pe less than 6 (Moreno-jiménez et al., 2012; Sadiq, 1997). Arsenate presents as dihydrogen arsenate ($H_2AsO_4^-$) and hydrogenarsenate ($HAsO_4^{2-}$) at neutral pH values. On the contrary, arsenite exists as arsenous acid (H_3AsO_3) at pH lower than 9.2 (Zhang and Selim, 2008). Arsenite is more mobile compared to arsenate which makes it more dangerous for human health. Mobilization of arsenic increase with an increment in pH (Moreno-jiménez et al., 2012). Thus, anions such as arsenate and arsenite are released (Moreno-jiménez et al., 2012; Zhang and Selim, 2008). Bissen and Frimmel (2003) state that for the prevention of arsenic mobilisation pH should not be in the alkaline range and redox potential should be high. Arsenate adsorption on clays and oxides depends on pH. Adsorption decrease with increasing pH thus mobility of arsenate increase. However, maximum adsorption of arsenite is observed for pHs between 8 and 10. Generally, arsenate is adsorbed more strongly than arsenite on soil constituents which means arsenite is more mobile and toxic (Zhang and Selim, 2008; Manning and Goldberg, 1997; Smith et al., 1999). Arsenate has higher adsorption capacity on soil constituents than arsenite at pH lower than 8 and competition between arsenate and arsenite is small (Zhang and Selim, 2008; Goldberg, 2002). Dixit and Hering (2003) have found a similar result which emphasize that arsenate adsorption is more possible than arsenite's at pHs lower than 7. In reducing environments arsenite is predominant among arsenic species while under oxidizing environments arsenate is superior (Moreno-jiménez et al., 2012). Bissen and Frimmel (2003) state that under reducing environments arsenic compounds are mobilised because bounds between Mn and Fe oxides are broken due to reduction of Fe^{3+} to Fe^{2+} and Mn^{3+} to Mn^{2+}. They also emphasized that reduction of these compounds begins at a redox potential of +200 mV under neutral and acidic conditions (Bissen and Frimmel, 2003). Mobility of arsenic decreases at a redox potential of -250 mV owing to precipitation of arsenic with iron sulfides which forms arsenopyrite, arsenic monosulfide or arsenic trisulfide (Bissen and Frimmel, 2003; Carbonell-Barrachina et al., 2000).

Figure 2.1 shows the transformations of arsenic species in soil. Owens et al. (2005) stated that arsenite and arsenate species can transform into methylated species or undergo chemical or microbial oxidation-reduction reactions which result with arsenic adsorption on hydrous oxides. Yang et al. (2012) have investigated partition distribution of arsenic between solid and soluble phase and concluded that pH is the most distinctive factor in phase partitioning.

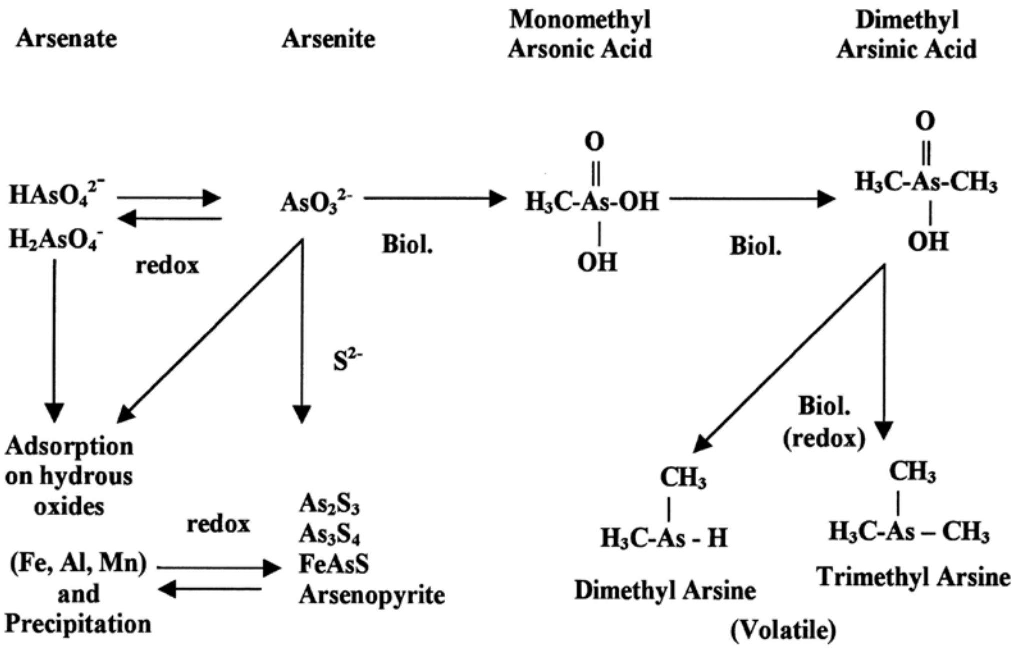

Figure 2.1. Transformations of arsenic in soil (Owens et al. 2005)

2.1.2. Oxides and Hydroxides

Arsenic activity in the soil is governed by the surface reactions with Fe, Mn, and Al oxides and hydroxides (Moreno-jiménez et al., 2012; Livesey and Huang, 1981; Fitz and Wenzel, 2002; de Brouwere et al., 2004). Retention and release reactions of As depends on the pH and Eh value of soil. Bounds of As with Fe and Mn oxides are broken under reducing environments and arsenic compounds that attached interior or surfaces of these hydroxides are released to the environment (Moreno-jiménez et al., 2012). Iron hydroxide, goethite, lepidocrocite, haematite, and akaganeite are the most important Fe oxides/hydroxides (Bissen and Frimmel, 2003). Some studies have shown that arsenite can be adsorbed on the surfaces of goethite and ferrihydrite (Lin and Puls, 2000). Adsorption of arsenate on Fe oxides/hydroxides (goethite, magnitite, and hematite) reduces when the pH increases (Zhang and Selim, 2008; Moreno-jiménez et al., 2012; Manning and Goldberg, 1997). Addition of the Fe to the soil reduces the mobility of arsenic and the adsorption of arsenic onto Fe oxides depends on the duration as the As release will be decrease with increasing time (Moreno-jiménez et al., 2012; Gräfe and Sparks, 2006).

2.1.3. Phosphates

Phosphate and arsenate compete not only for available adsorption sites but also for the complexation reactions and retention by oxides (Zhang and Selim, 2008;

Moreno-jiménez et al., 2012). Addition of phosphate to soil reduces the retention of arsenic due to competition between ions (Fitz and Wenzel, 2002). Violante and Pigna (2002) defined the distinctive terms that affect competition between arsenate and phosphate as residence time, concentrations, pH, and adsorbent properties. Madeira et al. (2012) have studied the effect of soil amendments on tomato and parsley growth. Calcium phosphate fertilizer added into contaminated soils in two different concentrations and results showed that mobility of arsenic increase with increasing fertilizer application, which results probably due to adsorption of phosphate fertilizer on soil constituents that cause release of arsenic.

2.1.4. Organic matter

Bañuelos and Ajwa (2017) express that organic matter has an essential mission on soil which is solubilization and cycling of trace elements and emphasize that toxicity of these elements may increase or decrease by organic matter in soil. Organic matter is a heterogeneous chemical nature which consist of different organic compounds that contain mostly carbon, hydrogen, oxygen, nitrogen and phosphorus elements (Moreno-jiménez et al., 2012). Yang et al. (2012) have studied As distribution between solid and soluble phase and concluded that one of the most influential factors determining the distribution is total organic carbon which represent organic matter. As a result of the study they have seen that arsenic is strongly bound to dissolved organic carbon in soil which reduces the adsorption onto other soil constituents. Romero-Freire et al. (2014) also found a similar result in their study which emphasize that organic matter was the most closely related variable related to reduction of arsenic mobility. Kar et al. (2013) have investigated arsenic, soil, and plant system and stated that organic matter and oxides are the major binding materials that capture arsenic. However, some studies showed that presence of organic matter may inhibit arsenic retention due to competition of adsorption on iron oxide surfaces (Redman et al., 2002).

Undoubtedly, one of the first substances that come to mind in terms of organic matter are fertilizers. Excessive use of arsenic containing fertilizers and manure in agricultural sites may increase arsenic concentrations in soil. Kabata-Pendias and Pendias (2001) have stated that additives used in breeding crops, especially phosphate fertilizers, contain high levels of arsenic up to 1200 mg/kg. Therefore, various countries have limited application rates of fertilizers products. US EPA requires maximum 0.018 kg/ha annual application of fertilizers to avoid extreme arsenic loading to soil (US EPA, 1999). Allowable levels of trace elements applied on agronomic sites can be reckoned depending on several factors. Soil characteristics, background trace element concentrations, interaction between elements and plant sensitivity are the most important factors to evaluate application of fertilizers (Kabata-Pendias and Pendias, 2011).

2.1.5. Clay Minerals

Clay soils tend to adsorb more arsenic compared to sandy soils due to its larger surface area (Owens et al., 2005; Walsh et al., 1977). Also, arsenate adsorbs to clay minerals more strongly than arsenite does (Moreno-jiménez et al., 2012). Kaolin, smectite, illite, and chlorite are the four main clay groups which have high surface areas and electrical charge. Cation exchange capacities of clay minerals differ significantly. Among them montmorillonite is the clay mineral type which has highest cation exchange capacity while kaolinite has the lowest one (Kabata-Pendias and Pendias, 2011, p.69). Ability of binding arsenic is directly related with cation exchange capacities. Adsorption of arsenic to clay minerals increase with increasing cation exchange capacity.

2.1.6. Microorganisms

Rhizosphere soil is the soil which is around the root area of the plant and microorganisms directly affect arsenic speciation in rhizosphere soil (Punshon et al., 2016; Gadd, 2010). Inorganic arsenic species can transform to organic species such as monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) (Punshon et al., 2016; Jia et al., 2013; Xu et al., 2016). Organic arsenic species transfer more easily from root to upper parts of the plants which implicitly increase arsenic uptake of humans (Punshon et al., 2016; Carey et al., 2011). Methanogenic and sulfate-reducing bacterias are responsible from methylation of arsenic and adsorption of arsenic on soil constituents reduces with the methylation process (Zhang and Selim, 2008; Cullen and Reimer, 1989).

2.1.7. Other factors

Sulfides and calcium carbonates also can affect arsenic adsorption and availability to the plants. Zhang and Selim (2008) state that weathering processes can release arsenic to nature via oxidizing arsenic in sulfide minerals to arsenate or arsenite. Realgar, arsenopyrite and orpiment are the most prevalent forms of arsenic containing sulfides (Farooq et al., 2016). Bostick and Fendorf (2003) observed that adsorption of arsenic on troilite and pyrite increased with elevated pH.

Romero-Freire et al. (2014) have studied about arsenic toxicity and transfer in relation to soil properties. Seven different soil types with different characteristics examined in order to determine most effective factors in arsenic accumulation to plant. At the end of the work they have found a linear relationship between bioavailable arsenic, pH and calcium carbonate content of soils. Highest toxicity values observed for highly carbonated soils with pH over 7 which reduced root elongation up to 50%. Additionally, inverse relationship also observed between water soluble arsenic, iron oxides and organic matter content. Reduction in the solubility of arsenic was recorded for the samples with high organic matter and iron oxide content. Bioavailability of arsenic increases with its solubility in soil. Organic matter and iron oxides capture arsenic in soil and lower its toxicity.

2.2. Arsenic and Plants

Arsenic concentrations in plants are highly related to the chemical composition of the growth medium. Response to chemical stress is different for every plant-soil system. Genotypic variations of plants deeply affect trace element accumulation. For instance, leafy vegetables tend to accumulate arsenic more than legumes and root vegetables (Kabata-Pendias and Pendias, 2011; Alexander et al., 2006). In that manner, plants can be divided into sections as arsenic resistant and non-resistant plants. Generally, there are three mechanisms which affect arsenic uptake: accumulation, indication, and exclusion (Kabata-Pendias and Pendias, 2011). While some plant species such as *Pteris vittata l.* and *Alopecurus pratensis* accumulate arsenic intensely to their body and named as hyperaccumulators, some of the species resist to arsenic with different mechanisms such as chelating of ions with outside plant cells (mostly roots) or selective uptake of ions (Kabata-Pendias and Pendias, 2011). Arsenate which is an analogue of phosphate is the dominant form of arsenic in aerobic soils. *Holcus lanatus*, *Calluna vulgaris* and *Silene vulgaris* have resistance to arsenic owing to their suppressing mechanisms which reduce arsenate influx to a level that the plant can detoxify itself (Meharg and Hartley-Whitaker, 2002). However, the fact that a plant is resistant to arsenic does not mean that it will never take it into its body. Resistant plants can still accumulate important amounts of arsenic as in the case of *Agrostis tenuis* and

H. Lanatus plants which contain upto 3470 and 560 µg/kg arsenate in their tissues respectively (Meharg and Hartley-Whitaker, 2002; Porter and Peterson, 1975).

2.2.1. Absorption of Arsenic

Even though the plants can absorb the arsenic from their leaves due to aerial deposition of arsenic, which is named as foliar uptake, main arsenic uptake resource is still root uptake from nutrient solutions or soil (Kabata-Pendias and Pendias, 2011, p.95). Trace element uptake mechanisms contain several processes such as cation exchange by roots, transport inside cells, and rhizosphere effects (Kabata-Pendias and Pendias, 2011, p.97). Root exudates controll rhizosphere processes thus absorption of arsenic. Processes that occur in the rhizosphere such as pH and Eh variations, mobility of nutrients, and formation of complexes affect arsenic absorption (Kabata-Pendias and Pendias, 2011, p.97). Uptake mechanisms of arsenic will be explained in the following section.

2.2.1.1. Root Uptake in the Literature

There is still limited data about transfer of arsenic species through roots. Transfer of arsenic species differ in uptake mechanisms. Arsenic species which found in terrestrial plants can be listed as; arsenate, arsenite, monomethylarsonic acid, dimethylarsinic acid, trimethylarsine oxide, tetramethylarsonium cation, arsenocholine, arsenobetaine, and arsenosugar (Meharg and Hartley-Whitaker, 2002). However, arsenate and arsenite are the most dominant species that found in the rhizosphere soil (Zhao et al., 2009). Arsenate is the superior arsenic variety which presents in the aerobic soils whereas arsenite dominates anaerobic environments such as flooded soils (Zhao et al., 2010). Arsenate and arsenite uptake mechanisms in plants differ due to their chemical structure.

Arsenate is an analogue of phosphate which shares same transport pathways (Zhao et al., 2009; Asher and Reay, 1979; Ullrich-Eberius et al., 1989; Meharg et al., 1994). These transport pathways have a higher affinity for phosphate which means phosphate in soils can inhibit arsenate transport (Zhao et al., 2009). While arsenate is taken from phosphate transporters in root cells, arsenite is taken by aquaporins (Zhao et al., 2010). Arsenite uptake may inhibited by glycerol and antimonite. Also, there are studies that indicate arsenite may share same transport pathway with Si due to their chemical similarities such as tetrahedral molecule shape (Zhao et al., 2009; Ma et al., 2008; Ma et al., 2006). Arsenic speciation in the root zone which named as rhizosphere can be different than the speciation in soil. Microbial activity and oxygen consumption in rhizosphere may transform arsenate to arsenite which results in coexistence of both species in aerobic soils (Zhao et al., 2009).

2.2.2. Arsenic metabolism in plants

Although the plants had been exposed to arsenate, arsenite is the predominant arsenic variety in the plant cells because it is reduced to arsenite in the plant cells by enzymatic or non-enzymatic reactions (Zhao et al., 2010; Zhao et al., 2009). Xu et al. (2007) have studied the arsenate reduction mechanisms in rice (*Oryza Sativa*) and tomato (*Lycopersicon Esculentum*). Tomato and rice which grown hydroponically were nurtured with arsenate and arsenite solutions to observe arsenic speciation in the plants. Treatments were repeated for 3 days with or without phosphate. After the first day of treatment with arsenate solution at a concentration of 10 µM in the absence of phosphate, total arsenic in the root of tomato was determined as 402 nmol/g. Arsenate, arsenite, and dimethylarsinic acid concentrations were 15.5, 237, and 0.1 nmol/g respectively. For the treatment with 10 µM arsenite solution without added phosphate, total arsenic concentration in the root was 542 nmol/g where arsenate, arsenite, and dimethylarsinic acid concentrations were 2.9, 371, and 0.5 nmol/g respectively. Results showed that an important portion of arsenate transformed into arsenite and dimethylarsinic acid in the plant cells. In a review article written by Zhao et al. (2009) it was stated that for the plant species such as barley, rice, tomato, indian mustard, and cucumber at least 59% of the arsenate transformed into arsenite and transformation ratio of arsenate to dimethylarsinic acid was maximum 3.7% in the experiments carried out. Based on the results, one can interpret that dominant arsenic species in the plant cells are inorganic species that pose more danger for human health via consumption.

2.2.3. Translocation

Translocation of arsenic can be defined as movement of arsenic from roots to aboveground parts of the plants. Translocation is specific for each plant type and differs with resistance mechanisms and sensitivity of the plant. Arsenic translocation is generally limited due to complexation of arsenite with thiols and sequestration in the vacuoles (an organelle in the plant cell) of root cells (Zhao et al., 2009). Baker (1981) distinguished plants into three section due to their arsenic uptake and translocation mechanisms. From his point of view, plants response to arsenic in three ways. ‘Accumulators’, concentrate trace metals easily in their aboveground parts while ‘excluders’ are not likely transport trace metals to their shoots which always have low concentrations. ‘Indicators’ show a linear relationship between external and internal levels of trace metals. Most of the terrestrial plants act as excluders for arsenic except ferns which are hyperaccumulators (Naidu et al., 2006, p.211).

2.2.4. Toxicity and Tolerance

Phytotoxicity of arsenic depends on the soil characteristics, arsenic speciation and plant type. Kabata-Pendias and Pendias (2011) define toxic effects of arsenic as growth reduction, cell plasmolysis, root discoloration, violet coloration due to increased anthocyanin, and leaf wilting. The author also stated that soil properties affect toxicity deeply. In the experiments which conducted to observe corn growth response to arsenic exposure, it has been seen that 1000 mg/kg arsenic in heavy soil and 100 mg/kg arsenic in light soil were equally toxic, and caused 90% growth reduction (Woolson et al., 1973). Heavy soil that used in the experiments contained high organic matter content and kaolinite clay while light soil contained low organic matter and vermiculite clay. Results showed arsenic does not transport to plants linear to soil concentration and soils with strong arsenic adsorbents are less toxic to plants. In the phytotoxicity review written by Sheppard (1992) spinach, bean, cucumber, and onion stated as high sensitivity plants while radish, potato, and corn were medium sensitivity plants. Cabbage, carrot and tomato considered as very tolerant.

Yoon et al. (2015) have studied phytotoxicity of arsenic on cucumber, wheat, broccoli, and 7 other species. For the study two types of soil were chosen. Soil A, had pH 5.1 and 3% organic matter content while Soil B had pH 4.3 and 0.3% organic matter content. Phytotoxicity tests were carried out for arsenate, arsenite, and dimethylarsinic acid. For the Soil A, no-observed-effect-concentrations (NOEC) for germination of plants which nurtured with arsenite were determined for cucumber, wheat, and broccoli as >500, 80 and 50 mg/kg respectively. For arsenate, NOEC values were determined for cucumber, wheat, and broccoli as >500, 200 and 150 mg/kg respectively. In the test with dimethylarsinic acid, NOEC values were found the same as arsenate for cucumber and wheat but there is no data given for broccoli. For the Soil B, NOEC values for germination of cucumber and wheat which nurtured with arsenite were found as 160 and >640 mg/kg respectively. For the experiments which conducted with dimethylarsinic acid, NOEC values were found same as arsenite. For arsenate, wheat and cucumber had the same NOEC levels with >640 mg/kg. In the growth reduction tests which conducted for arsenite, NOEC levels for cucumber were found as 50 and 40 mg/kg for Soil A and Soil B respectively. Wheat had the same NOEC level in Soil A with cucumber (50 mg/kg). However, this value elevated to 80 mg/kg in Soil B. An interesting result found in the study was that wheat had 40 mg/kg NOEC level for dimethlarsinic acid which always thought as less toxic than arsenite to the plants. As a conclusion of the study, it was seen that phytotoxicity of arsenic species are hard to interpret and seriously differs among plants and soil types.

Kader et al. (2016) conducted a similar study to investigate phytotoxicity of arsenic on cucumber and wheat with a point of view that concentrated on sorption parameters in soil. Seven uncontaminated soils from Australia were used for the study. Soil types were vertosol, kurosol, ferrosol, dermosol, tenosol, and calcarosol. As the phytotoxicity test root elongation method was used. Reduced root elongation is a common situation in plants which exposed to arsenic therefore measurement of root elongation is a reasonable and easy method to understand arsenic toxicity. For wheat, minimum EC50 level was observed as 97.72 mg/kg and maximum EC50 level was 562.34 mg/kg. When the two soil types are compared, the soil which maximum value was observed had higher pH (7.73) and lower organic matter and clay content, cation exchange capacity, and ferrous oxide content. Minimum and maximum EC50 levels were observed for the same soil types for the cucumber. Maximum EC50 level was 380.19 mg/kg and minimum was 41.69 mg/kg. In conclusion, it was seen that adsorbents on soil reduce arsenic availability for plants and cucumber is more sensitive to arsenic compared to wheat.

Consequently, it can be said that it is impossible to interpret phytotoxicity based solely on total arsenic concentrations. Adsorption mechanisms on soil deeply affect arsenic bioavailability and phytotoxicity. Also, arsenic speciation should be known since inorganic species generally thought to be more toxic to plants but some studies concluded otherwise.

2.2.5. Plant Concentrations

Kabata-Pendias and Pendias (2011) state that plants which breed in uncontaminated soils have arsenic concentrations in a range of 5 to 80 µg/kg. However, for the plants that breed in the contaminated areas there is no certain threshold concentration which specify an upper limit. Even so, it can be said that plants reach excessive levels of arsenic when they have 5 to 20 mg/kg arsenic in their tissues (Kabata-Pendias and Pendias, 2011).

Antoniadis et al. (2016) measured vegetable concentrations in the vicinity of former mining area in Germany. Carrots, beans, and lettuces planted in the four different garden were examined. Soil arsenic concentrations range between 15 to 267 mg/kg. Highest concentration was observed for the root of the lettuce which is approximately 8 mg/kg. Highest concentration in the edible parts of the plants was also observed for lettuce leaf which had higher concentration than 4 mg/kg. Bean seeds had concentrations greater than 3 mg/kg and carrot root had approximately 1 mg/kg arsenic.

Baroni et al. (2004) conducted a similar research on vegetation in the vicinity of former mining area in Italy where the total arsenic concentration ranged between 5.3 to 2035 mg/kg. Corn, sunflower seed, lettuce, wheat, eggplant, and tomato were some of the vegetable species in which arsenic concentrations measured. Among the species the highest arsenic concentration was observed in lettuce leaves as 0.13 mg/kg. Wheat, corn, and sunflower seed had similar concentrations that ranged between 0.02 to 0.03 mg/kg. Arsenic concentrations in eggplant leaves were measured as 0.11 mg/kg. Arsenic concentration in tomato fruits were lower than 0.02 mg/kg.

Warren et al. (2003) have studied arsenic uptake by vegetables in the vicinity of a former arsenic smelter. Soil samples contained arsenic up to 748 mg/kg in the most contaminated site. Cauliflower, lettuce, potato, radish, and spinach were the investigated species. The highest arsenic concentration was measured in radish tuber as 8.39 mg/kg. Lettuce also had a high concentration which was 6.77 mg/kg. Potato tuber and broccoli had relatively low concentrations of arsenic which are respectively 0.1 and 0.09 mg/kg. Arsenic concentration of spinach was 0.49 mg/kg while cauliflower had a concentration of 0.64 mg/kg.

Alam et al. (2016) have studied relation between arsenic contaminated groundwater, soil, and crops in India. Arsenic contaminated groundwater contained 23 to 176 µg/L arsenic which is above WHO limit value for drinking waters (10 µg/L). Arsenic concentrations in soil ranged between 3.92 to 7.05 mg/kg. Bioavailable arsenic varied from 0.06 to 1.58 mg/kg. Wheat, corn, spinach, tomato, cucumber, eggplant, okra, potato, onion, radish, and garlic were some of the studied species. Arsenic concentrations in the edible parts of the plants varied between 0.04 to 0.21 mg/kg dry weight. Among the species, the leader was wheat with 0.21 mg/kg while okra had minimum value with 0.04 mg/kg. Since spinach is a leafy vegetable, arsenic accumulation to plant tend to be higher. Arsenic concentration of spinach was found relatively high as 0.17 mg/kg. Fruity vegetables such as eggplant, okra, cucumber, and tomato had arsenic concentrations ranged between 0.05 mg/kg to 0.12 mg/kg. Arsenic concentrations in potato and onion were found as 0.1 and 0.07 mg/kg respectively. Garlic had the highest arsenic concentration among the bulbous and tuberous vegetables with 0.18 mg/kg. Radish had a concentration of arsenic with a level of 0.11 mg/kg. When accumulation of arsenic from soil to plants was examined, it was seen that highest accumulation was belonged to eggplant among the mentioned vegetables. However, the highest translocation factor belongs to radish which means radish transfers the arsenic to its aboveground parts more effectively.

In conclusion, arsenic transfer to plants is a hard to interpretable issue which requires more information on arsenic uptake dynamics. Contaminated plant concentrations differ due to soil properties, arsenic speciation, and plant features. There is still limited data about limit levels of arsenic which a plant can contain. No data could be obtained about when plants stop arsenic transfer to their tissues according to the change of soil characteristics. There is an exigency in the literature for explanation of the question “At what level is the arsenic from soil can be transferred into plant and how soil types or characteristics affect that level?”.

CHAPTER 3

HUMAN HEALTH RISK ASSESSMENT

3.1. Health Effects of Arsenic

Arsenic exposure may cause either acute or chronic health effects. Acute effects are the rapidly developed severe symptoms which can result from excessive exposure to a chemical substance. Vomiting, diarrhea, tachychardia, hypotension, altered mental status, nausea and dizziness are the general acute effects of arsenic on humans (Blumenberg et al., 2017). Acute effects mostly diminish when the exposure source is identified and removed. Exposure to arsenic in small quantities over a long period of time is more commonly observed. Therefore, mostly chronic effects of arsenic is observed. Arsenic targets enzyme reactions and affects almost all organ systems. Lung, liver, kidney, skin and bladder cancers strongest associated diseases with chronic arsenic exposure (Abernathy et al., 1999). Also, skin symptoms such as hyperpigmentation, small focal keratosis, hyperkeratosis are observed frequently (Hong et al., 2014).

For the areas that arsenic concentrations not naturally elevated, food products conduce to daily intake on a large scale. Fish, rice, cereals, dairy products and shellfish are the foods which contain higher levels of arsenic (Ahmed et al., 2016). World Health Organization, was recommending 15 µg/kg body weight provisional tolerable weekly intake of arsenic as a limit value until 2010. However, toxicity studies have shown this value was in the region of benchmark dose for a 0.5% increased incidence of lung cancer and therefore is no longer appropriate (WHO, 2010). As a result, WHO requires 2.1 µg/kg- BW/day limit as provisional tolerable daily intake since 2011 (WHO, 2011).

3.2. Risk Assessment

Risk assessment is an effective tool for defining and evaluating possible risks to human health caused from exposure to diverse pollutants. It uses toxicity data for chemicals that humans are exposed and estimates possible risk levels.

For the purpose of that, four-stage flow chart created by research council of National Academies is frequently used (National Research Council, 1983). First step is the ‘Hazard Identification’ which identifies the health problems caused by the pollutants. Hazard Identification answers questions such as ‘What are the consequences of being exposed to this pollutant?' and assesses the weight of evidence supporting this identification. If an agent is identified as an hazard, the second step in the flow chart is 'Dose-Response Assessment' which describes the probability and intensity of the health effects in relation to the quantity and condition of exposure to a pollutant. 'Exposure Assessment' is the third step which estimates duration, frequency and magnitude of the exposure. Lastly, 'Risk Characterization' is the step that transmits the assessor's decision about the presence of risk and how it will be managed. Among these steps, first two are specific and objective for each chemical whereas last two steps dependent on the risk assessor and exposure scenario. Epidemiologists, toxicologists, chemists, medical researchers and engineers participate in different stages of the risk assessment process.

3.2.1. Hazard Identification

Hazard Identification is the process of identifying whether exposure to a chemical agent can cause an increment in the occurrence of particular health effects. Statistically controlled studies on humans generally compensate best proof for linking an agent to a health outcome (US EPA, 1986). However, it is hard to obtain data from humans due to ethical values. Therefore, epidemiological studies is carried out frequently. Benefit of these studies is that they connect an association between a human health effect and a stressor statistically. Data from animal studies is used to link stressors to health effects when data from human studies are absent. These studies can be canalized to fill certain gaps in information yet there are uncertainties due to physiologic differences between humans and animals. Chemical agents mainly divided into two parts as carcinogenic chemicals and non-carcinogenic chemicals although some chemicals have both carcinogenic and toxic effects. US EPA, classifies chemicals through their potential to create carcinoma. Hierarchic categories can be seen in Table 3.1. US EPA has classified arsenic as a Group A- Human Carcinogen depended on sufficient proof from human studies.

Table 3.1. Carcinogenicity classification of chemicals by US EPA (1986)

Group	Category
A	Carcinogenic to Humans
B	Probable Human Carcinogen
	B1 limited evidence of carcinogenicity from epidemiologic studies
	B2 carcinogenicity evidence from animal studies and inadequate/no evidence from epidemiologic studies

(Cont. on next page)

Table 3.1. (Cont.)

Group	Category
C	Possible Human Carcinogen
D	Not classifiable as to human carcinogenicity
E	Evidence of non-carcinogenicity for humans

3.2.2. Dose-Response Assessment

Dose is the quantity of an chemical agent received by biological receptors upon exposure (Asante-Duah, 2002). Dose-Response assessment refers to relationship between a quantified dose and a particular biological response. Generally, response increases with increasing dose. However, at low doses, response may not be observed.

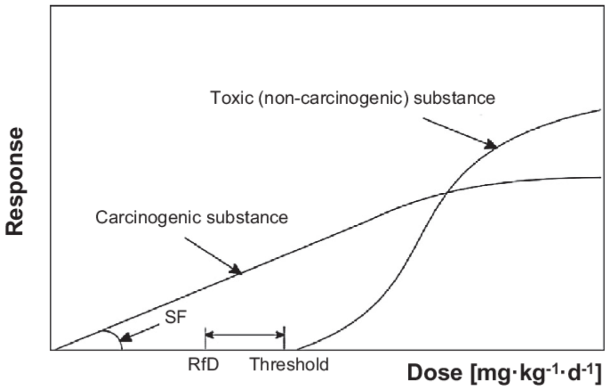

Figure 3.1. Dose-Response curve of carcinogenic and non-carcinogenic substances

Asante-Duah (2002) defines dose-response curve as "a graphical representation of the relationship between the degree of exposure to a chemical substance and the observed or predicted biological effects or response". Figure 3.1 shows dose-response relationship. Reference dose (RfD) expresses the maximum quantity of a non-carcinogenic chemical agent which can be absorbed by organism without experiencing chronic health effects (mg of chemical/kg body weight/day) (Asante-Duah, 2002, p.317). RfDs are calculated by dividing No-Observed-Adverse-Effect-Level (NOAEL) doses obtained from toxicity studies to proper uncertainty factors. The NOAEL expresses the utmost level that an agent creates no observable adverse effects in the tested or exposed population. For the situations which NOAEL values do not exist, Lowest-Observed-Adverse-Effect-Level (LOAEL) can be used instead (US EPA, 1993). LOAEL is the lowest dose of an agent causing biological or statistical increment in severity of adverse effects. For the carcinogens, it is thought that any exposure will lead to the possibility of cancer. Slope or potency factor is the slope of the dose-response curve and defined as cancer risk per unit dose. Reference dose and slope factor values are particular for each chemical agent and exposure route. Reference dose for oral exposure and oral slope factor of arsenic values are 0.0003 mg/kg-day and 1.5 per mg/kg-day respectively (US EPA, 1988).

3.2.3 Exposure Assessment

Exposure assessment step answers the questions about magnitude, duration, and frequency of exposures or estimates future exposures that have not been released yet (National Research Council, 1983). Dermal absorption, inhalation and ingestion are the three primary routes of exposure. In this study only ingestion route was considered in order to assess exposure related with arsenic contamination in plants. Chronic Daily Intake (CDI) is used to calculate risk and is expressed as absorbed mass of an agent per unit body weight per unit time throughout of exposure (Asante-Duah, 2002). Chronic daily intake expresses exposure of the receptor averaged over a long period of time (Asante-Duah, 2002, p.302).

3.2.4. Risk Characterization

Final step in the exposure assessment process takes all former steps into consideration to assess an overall risk. Risk characterization step amalgamates dose-response assessment data with exposure assessment data to bring forth a quantitative estimate of risk. Risk values greater than 10^{-6} indicates risk and defined as unacceptable by US EPA (US EPA, 1996). Nevertheless, in accordance with environmental policies and standards, this value can be up to 10^{-4}. US EPA (2001) set the maximum contaminant level of arsenic in drinking water as 10 µg/L. For the determination of maximum contaminant level, US EPA used the results of lung cancer risk research and found that cancer risks would be about one in ten thousand at 10 µg/L of arsenic water concentration. Thus, 1 in 10,000 risk estimate for arsenic can be assumed as acceptable risk level. Hazard Quotient is the ratio of a chemical’s exposure level for a certain time to tolerable intake limit of that chemical. Hazard quotient values greater than 1.0 (the threshold limit) represents a potential to significant risk and adverse health effects. However, estimated risks around the threshold may be within the uncertainties involved.Therefore, an arbitrary two-folds difference is considered to claim either significance or non-significance for the estimated risks. In this study, risks are classified as with the boundaries listed in Table 3.2.

Table 3.2. Classification of carcinogenic and non-carcinogenic risks

Carcinogenic Risk		Non-carcinogenic Risk	
$R < 10^{-6}$	Acceptable	$HQ < 0.5$	No Concern
$10^{-6} \leq R < 10^{-4}$	Considerable	$0.5 \leq HQ < 2$	Concern
$R \geq 10^{-4}$	Significant	$HQ \geq 2$	Significant

3.3. Deterministic and Probabilistic Approach

Exposures can be calculated as deterministic or probabilistic depending on the purposes of the evaluation. Deterministic approach operates point values with scenarios to create point estimates of exposure. On the other hand, probabilistic approach forms a probability distribution which uses data distributions for variables instead of point values. Herewith, probabilistic approach creates almost all possible scenarios to be able to have a probability description for the population under study.

In the probabilistic approach, risk assessors must fit distributions to input parameters. Therefore, it requires more expertise and time than deterministic approach. Computer-based simulations are frequently used for probabilistic approaches in the interest of saving time and effort.

3.3.1. Monte-Carlo Simulation

Monte-Carlo simulation is a computer-based probabilistic method which serve for forecasting and predicting purposes in risk assessment. All independent variables are entered into the exposure-risk models as probability distributions, such as duration, body weight etc. and defines possible values. Crystal ball software is used for simulation and fitting the probability distributions. Then, dependent variables identified as forecasts. Values are randomly selected from the defined distributions and forecasts are calculated for each sole trial. If the software is run for ten thousand trials then ten thousand outcomes are calculated. Thus, 10,000 times enhanced range of possibilities is obtained via this software when compared with the single value in deterministic approach, which are used to construct the population distribution.

3.4. Arsenic Exposure-Risk Assessment Studies in the Literature for Edible Plants

Antoniadis et al. (2016) have investigated potential toxic elements in edible vegetables in the vicinity of former mining area. Study site was located in North Rhine-Westphalia, Germany, where the geological content mostly sandstone and silty clay stone. Research area is divided into four section according to organic matter content, pH values and the growing plant species. For all sections, trace elements were found in high concentrations. Especially, arsenic concentration in one of the gardens (267.2 mg/kg) was higher than the regulation limits (50 mg/kg). Cultivated plants , green beans (*Phaseolus vulgaris*) carrots (*Daucus sativus*) and lettuce (*Lactuca sativa ssp. capitata*) seperated into parts (leaf,seed,shoot and root). Different parts of plants microwave acid digested and analyzed with ICP-OES. As a result of the examinations, it was seen that arsenic accumulations in plants decrease from roots to seeds. Arsenic concentrations found higher than 7 mg/kg in the roots of lettuce and beans. For the edible parts of the plants , arsenic concentrations were up to 5 mg/kg. Health risks related with vegetable consumptions deterministically assessed. Despite the high concentrations that found in the plants , daily intake values found lower than the WHO regulations (2.1 mg As per kg bodyweight per day). Daily intake values found as 0.40, 0.12 and 0.33 mg As per kg bodyweight per day for beans, carrot and lettuce respectively. All hazard quotient values were below the 1.0 which indicates there is no potential non-carcinogenic risk for the consumption of these vegetables. These outcomes may resulted from deterministic approach which uses single values for the variables.

Ahmed et al. (2016) assessed arsenic exposure via commonly consumed foodstuffs in rural and urban populations in Bangladesh. For the purpose of that, cereals, pulses, meat, milk, eggs, fish, fruits and vegetables are investigated. Brinjal, carrot, beans, potato, tomato, onion and green chili are the investigated vegetables. Among all the foodstuff, cereals have highest concentrations of total arsenic which is followed by pulses (chickpea) and vegetables (potato). Average fresh weight concentration of vegetables ranged between 0.25 mg/kg to 0.35 mg/kg. For the Bangladeshi population highest consumption rate among vegetables belongs to potato (67.08 g/day for urban and 71.74 g/day for rural). Highest estimated daily intakes are observed for bean in rural population (0.093 µg/kg-BW/day) and for brinjal in urban population (0.078 µg/kg-BW/day). When relative contributions of foodstuffs to daily

Arsenic intake were examined, it was seen that vegetables have 25% of the daily dietary intake of arsenic. Total daily dietary intake of Arsenic was found as 3.5 µg/kg-BW/day for the rural and 3.2 µg/kg-BW/day for the urban. Both population have exceeded the current regulation which is 2.1 µg/kg- BW/day (WHO, 2011).

Kar et al. (2013) have investigated the transfer of Arsenic from soil to plants and assessed the potential health risks. The study area is located on the coastal part of Chianan Plain in southwestern Taiwan. Thirteen vegetable species analyzed in order to find arsenic concentrations in different parts of the plants. Highest As concentration in edible parts of the plants is observed for mustard (*Brassica Juncea*) with 75.8 µg/kg of fresh weight and tomato (*Lycopersicon esculentum*) had the second highest concentration with 53.4 µg/kg of fresh weight. Arsenic concentrations ranged between 9.15 to 75.8 µg/kg. Maximum consumption rate for the vegetables belongs to cabbage with 41.2 g/day/person. Health risk index of vegetables is calculated deterministically and found as 0.883 which is lower than the threshold limit. Biggest hazard quotient value was calculated for tomato (approximately 0.08). However, results have shown no significant potential hazards.

In conclusion, it was seen that there are not sufficient studies in the literature about risk assessment of the arsenic contaminated vegetables. There is an exigency in the literature for the risk assessment of arsenic contaminated foodstuffs.

CHAPTER 4

MATERIALS AND METHODS

4.1. Study Location

Simav Plain is located in the Simav District of Kütahya Province in Turkey. Approximately 64,000 people reside in the villages and center of Simav according to the 2016 census results (TSI, 2016). Simav has a Mediterranean climate which is generally characterized by hot and dry summers, and rainy winters (Güneş, 2010). Based on the data from the The Turkish State Meteorological Service collected between 1995 and 2008, mean annual temperature of the region is 12.2 °C. The month with the highest average annual temperature in Simav is July with 22.9 °C, while January have the lowest average annual temperature with 2.6 °C. The average annual maximum temperature reached its highest in July at 35.7 °C. The average annual minimum temperature is the lowest in January at -9.6 °C. Simav District receives annual average precipitation of 750.4 mm. December is the month with the most rainfall, while July is the driest month (Güneş, 2010; TSMS, 2009).

Simav District has 168,675 ha total soil area. Brown forest soils are the main soil type in covering an area of 76,950 ha. Non-calcareous brown forest soils follow brown forest soils with 66,796 ha. Alluvial, colluvial, organic, and non-calcerous brown soils and rendzinas are the other soil types in the district (Kütahya İl Çevre Durum Raporu, 2011; Kütahya Directorate of Provincial Food Agriculture and Livestock, 2011). In the study conducted by Güneş (2010) soil features of the agricultural land in the district were investigated. In this context, organic matter, pH, saltiness, pH, elemental content, and soil texture were studied. According to the study, in the agricultural land average pH was found as 7.8 which signifies slightly alkaline soil. Total saltiness, organic matter, and $CaCO_3$ were found as 557.6 mS/m, 9.03% and 8.7%, respectively. Nitrogen and phosphorus content of the agricultural soil were found 0.21% and 1.2%. Soil texture of the agricultural land consist of 26.03% sand, 47.09% clay, and 26.88% silt. Sodium content were found 80.05 mg/kg in the agricultural land. Based on the pH (7.8) it is expected that the dominant specie in the soil environment would be arsenate (Moreno-jiménez et al., 2012). High clay content and organic matter adsorb arsenic (Romero-Freire et al., 2014; Warren et al., 2003). Therefore, decreased arsenic mobility is also expected in the Simav agricultural soil. In 2011, the consumption of chemical fertilizer in Simav District was reported to be about 4 tons (Kütahya İl Çevre Durum Raporu, 2011). Even though the organic matter in the fertilizers reduces the arsenic mobility, some fertilizers may contain arsenic , therefore create contamination hazard for the crops and soil (Kabata-Pendias and Pendias, 2001). Soil arsenic concentrations in Simav plain were measured by Gündüz et al. in a TÜBİTAK project in 2012. Soil samples were collected from fifteen sampling points at several depths in and around the plain. Collected samples were grinded and extracted with nitric acid then analyzed with ICP-MS. Figure 4.1 shows the study area and the sampling points. The soil arsenic concentrations ranged between 18 to 113 mg/kg. The highest arsenic concentration were observed on sampling point 7 (SK-7) at fifth meter depth as 113 mg/kg. Arsenic concentrations in the first and fifth meter soil samples are listed in Table 4.1.

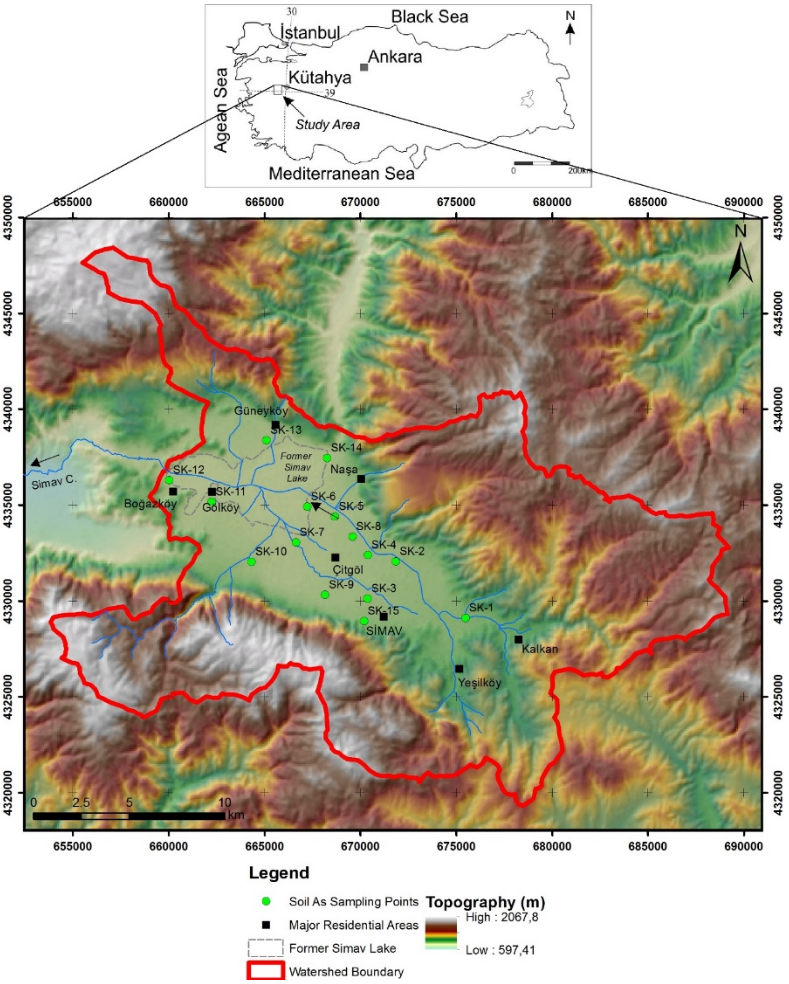

Figure 4.1. Study location and soil sampling points (Gündüz et al., 2012)

Table 4.1. Soil Arsenic Concentrations in the Agricultural Area of Simav

Sampling Points		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
As (mg/kg)	**1 m**	59	53	36	44	60	71	92.5	46	55	29	53	35	56	18	33
	5 m	46	26	37	45	26	48	113	29	26	58	75	22	37	22	31

4.2. Plant production in Simav

Edible plants species grown in Simav were gathered from Turkish Statistical Institute (TSI) database. Bean, broccoli, cabbage, carrot, cauliflower, corn, cucumber, eggplant, garlic, lettuce, okra, onion, potato, radish, spinach, sunflower, tomato and wheat are the plant species which commonly produced in Simav. Table 4.2 shows production rates of these species in Simav.

Table 4.2. Production rates of edible plant species in Simav

Scientific name	Common Name	Production rate in 2016, tons/year
Phaseolus Vulgaris L.	**Bean**	621
Brassica Oleracea Var. İtalica	**Broccoli**	14
Brassica Oleracea Var. Capitata F. Alba	**Cabbage**	270
Daucus Carota	**Carrot**	4
Brassica Oleracea Var. Botrytis	**Cauliflower**	180
Zea Mays	**Corn**	1121
Cucumis Sativus	**Cucumber**	987
Solanum Melongena	**Eggplant**	5
Allium Sativum	**Garlic**	2320
Lactuca Sativa	**Lettuce**	235
Abelmoschus Esculentus	**Okra**	48
Allium Cepa	**Onion**	6160
Solanum Tuberosum	**Potato**	13355
Raphanus Sativus L.	**Radish**	72
Spinacia Oleracea	**Spinach**	320
Helianthus Annuus	**Sunflower**	14
Lycopersicon Esculentum	**Tomato**	16977
Triticum Aestivum	**Wheat**	30501

Wheat *(Triticum Aestivum)* was the most widely cultivated plant with 30,501 tons of production in 2016 among the chosen species. Tomato (*Lycopersicon Esculentum)* followed wheat with 16977 tons/year. Potato, onion, garlic, and corn also broadly produced with over 1000 tons a year.

4.3. Exposure – Risk Estimation

Equation 4.1. is used for determination of arsenic daily intake via consumption of plants. Exposure assessment using equation 4.1 considers consumption from both potentially contaminated produce grown in contaminated soils of Simav Plain and those that are not. Averaging time is the time period over human exposure to a chemical is measured (Asante-Duah, 2002, p.299). For the non-carcinogenic risk assessment, averaging time is equal to exposure duration because toxic effects arise while exposure. However, carcinogenic effects of chemicals can emerge throughout life. Hence, averaging time is equal to lifetime in carcinogenic risk assessment.

$$CDI = \frac{[(CP_Z \times PIR_Z \times FI_Z)+(BCP_Z \times PIR_Z \times (1-FI_Z)] \times ABS_S \times EF \times ED}{BW \times AT} \qquad (4.1.)$$

CDI = Chronic daily intake of arsenic from ingestion of plant type Z, mg/kg-day
CP_z = Arsenic concentration in plant type Z from contaminated source, mg/kg
BCP_z = Background arsenic concentration in plant type Z from uncontaminated source , mg/kg
FI_z = fraction of plant type Z ingested from contaminated source, unitless
PIR_z = average consumption rate for plant type Z, kg/day
ABS_s= bioavailability, %
EF = exposure frequency, days/years
ED = exposure duration, years
BW = body weight, kg
AT = averaging time, period over which exposure is averaged, days

Exposure frequency was assumed as 350 days/year by considering an absence of 15 days from the place of residence in a year (US Environmental Protection Agency, 2011). Average lifetime was assumed as 75 years in all scenarios according to The World Bank data for Turkey in 2017.

Cancer risk of arsenic exposure via ingestion route is calculated by using the equation 4.2.

$$R = CDI \times SF \qquad (4.2.)$$

where:
R= probability of lifetime cancer risk , unitless
CDI = Chronic daily intake of arsenic from ingestion of plant products, mg/kg-day
SF= Slope factor of Arsenic, $(\text{mg/kg-day})^{-1}$

Non-carcinogenic risk of arsenic exposure via ingestion route is calculated by using the equation 4.3.

$$HQ = \frac{CDI}{RfD} \qquad (4.3.)$$

where:

HQ= hazard quotient , unitless

CDI= Chronic daily intake of arsenic from ingestion of plant products, mg/kg-day

RfD= Reference dose for oral exposure, mg/kg-day

In this study only exposure to inorganic arsenic via ingestion of the edible plants was considered due to inorganic arsenic species are dominant in the plant tissues (Zhao et al., 2010). Required data for the calculations of chronic arsenic daily intakes were obtained from the literature. Plant species to be studied were chosen among the edible plants that are cultivated in Simav.

4.4. Consumption Rates of the Edible Plants

Consumption rates were obtained from Turkish Statistical Institute database. Exposure Factors Handbook was used for unvailble data in the database. Table 4.2 shows per capita consumption rates of the chosen plants as annual averages between 2000 and 2014 with the exceptions of 2005 and 2006. Carrot, sunflower seed, and corn are the species with the highest relative standard deviations while wheat, and tomato have the lowest relative standard deviations. Consumption rates were not available for broccoli and cauliflower from TSI database. Hence consumption rate data for broccoli and cauliflower were compiled from Exposure Factors Handbook as 6 g/day and 1.9 g/day respectively. As seen in table 4.2, most consumed plant is wheat with approximately 593 g/day in average for Turkish people due to its broad use in foods and pastries. Tomato is the second most consumed plant with averagely 308 g/day on average. It is also widely used in foods as tomato paste, puree or sauce. Potato and sunflower seed are came after wheat and tomato with 74 g/day and 62 g/day respectively. Consumption rates of sunflower seed are especially high due to usage of sunflower seed oil. In this study, alterations in the arsenic concentrations of plants that occur during cooking and during the production of products, such as sunflower oil and tomato paste, are not considered due to scarcity of the related information in the literature.

Table 4.3. Edible plant consumption rates of sixteen plant species in Turkey

	Consumption Rates Per Capita g/day															
Year	**Corn**	**Potato**	**Sunflower seed**	**Okra**	**Tomato**	**Carrot**	**Garlic**	**Onion**	**Cabbage**	**Lettuce**	**Eggplant**	**Radish**	**Spinach**	**Wheat**	**Bean**	**Cucumber**
2014/'15	47.2	132.6	76.1	1.0	327.4	16.1	2.4	54.1	22.4	13.8	25.3	6.0	6.3	550.2	8.2	50.5
2013/'14	41.4	122.0	89.3	1.1	326.7	16.6	2.4	53.8	22.4	13.6	25.7	5.6	6.8	583.6	8.3	50.6
2012/'13	52.2	142.1	91.5	1.2	321.1	20.9	2.1	52.4	22.2	13.3	25.3	4.6	7.0	617.4	8.1	51.0
2011/'12	44.7	148.9	112.3	1.2	313.9	17.8	2.2	65.5	19.9	13.6	26.4	5.1	7.0	626.6	8.2	52.3
2010/'11	46.9	144.5	90.6	1.2	290.0	15.7	2.1	60.0	19.8	13.6	27.6	5.1	6.9	585.9	8.9	52.0
2009/'10	45.4	145.3	78.2	1.3	309.6	17.6	2.3	60.5	20.4	14.4	27.2	5.3	7.3	547.3	8.0	52.0
2008/'09	39.9	139.1	78.9	1.3	326.3	18.2	2.3	62.6	19.8	14.6	27.4	5.5	7.4	592.2	6.4	51.7
2007/'08	39.8	135.4	83.9	1.3	300.8	20.3	2.2	58.1	19.1	14.5	29.1	5.4	7.9	566.1	7.7	52.7
2004/'05	49.9	159.6	65.4	1.5	291.0	13.9	2.4	68.3	20.4	12.2	30.7	5.9	7.2	586.5	10.5	55.4
2003/'04	70.6	173.5	57.4	1.2	309.7	12.8	2.8	58.7	21.5	11.6	32.4	6.0	7.6	580.4	7.9	58.2
2002/'03	54.4	174.9	38.4	1.0	305.4	6.6	2.3	66.2	21.5	12.0	33.5	6.2	7.7	622.7	8.6	55.0
2001/'02	59.2	170.2	58.7	1.0	278.0	7.3	2.5	71.2	21.5	12.3	33.7	6.0	7.4	630.7	9.0	58.7
2000/'01	56.0	185.4	45.2	1.0	301.4	7.4	2.4	75.3	22.2	11.9	33.4	6.1	7.4	617.6	8.8	63.5
average	49.8	151.8	74.3	1.2	307.8	14.7	2.3	62.1	21.0	13.2	29.0	5.6	7.2	592.8	8.3	54.1
SD[a]	8.7	19.2	20.6	0.1	15.5	4.9	0.2	7.0	1.2	1.1	3.3	0.5	0.4	28.3	0.9	3.9
RSD[b] **%**	17.5	12.6	27.8	11.4	5.0	33.1	8.0	11.3	5.5	8.0	11.3	8.6	6.0	4.8	11.1	7.2

a Standard deviation

b Relative standard deviation

4.5. Bioconcentration Factors of the Edible Plants

Bioconcentration factor can be defined as the ratio of arsenic concentration in edible parts of the plants to arsenic concentration in soil (Asante-Duah, 2002, p.300).

$$BCF = \frac{C_{plant}}{C_{soil}} \qquad (4.4.)$$

One can calculate arsenic concentrations in plants according to the formula below by using soil arsenic concentrations and bioconcentration factors.

$$C_{plant} = BCF \times C_{soil} \qquad (4.5.)$$

Web of Knowledge, Google Scholar, Science Direct and Scopus databases were searched for studies that reported bioconcentration factors for the edible plant species investigated in this study. Only, eleven articles were found showing that there are very limited data about bioconcentration factors for the vegetables. Table 4.3 shows bioconcentration factor data for the chosen plant species.

4.6. Background Arsenic Concentrations of the Edible Plants

Natural arsenic concentrations in plants were researched in the literature databases. Most of the data were obtained from a food survey which conducted by University of Aberdeen (Norton et al., 2012). Other data were obtained from different journal articles and a reference book for uncontaminated samples (Kabata-Pendias and Pendias, 2011). Table 4.5 shows natural background arsenic concentration for the subject.

4.7. Root depths of the Edible Plants Species

Root depth affects arsenic uptake of plants since arsenic concentrations in soil differs with depth. Table 4.6. shows root lengths of the subject species. Root lengths of five species (cucumber, eggplant, tomato, sunflower and wheat) exceed 1 meter while all other species remain under this value. For the first 1 meter of the soil, average arsenic concentration is 49.4±18.4 mg/kg which is higher than average arsenic concentration in the fifth meter (42.8±24.4 mg/kg). Table 4.6 shows root depths of the edible plant species.

4.8. Bioavailability of Arsenic in the Plants

For the evaluation of physiologically available Arsenic in human body, bioavailability values were obtained from the literature. Even though there are many studies about arsenic bioavailability in contaminated soils and dust recently, there are still limited information about arsenic bioavailability in foods. Juhasz et al. (2015) studied arsenic bioavailability in radish and lettuce and found that 77% and 50% of arsenic was physiologically available for the human body respectively. Pizarro et al. (2016) found that 98% of arsenic from carrots is bioavailable. Bioavailability data could not obtained for any other plant species thus assumed as 100% for a conservative approach.

Table 4.4. Bioconcentration factor values (unitless) retrieved from the literature

Bean	0.15[b]							
Broccoli	0.0012[k]	0.0012[k]	0.0012[k]	0.0003[k]				
Cabbage	0.33[g]	0.02[f]	0.05[f]	0.0018[e]	0.0029[e]	0.0022[e]		
Carrot	0.03[g]	0.03[b]	0.001[d]					
Cauliflower	0.03[g]	0.001[d]	0.0009[k]	0.0005[k]	0.0008[k]	0.0001[k]		
Corn	0.0007[j]	0.0004[j]	0.0011[j]	0.0009[j]	0.0004[j]	0.0036[j]		
	0.0043[a]	0.0038[e]	0.0061[e]	0.0046[e]	0.032[i]	0.031[i]		
	0.029[j]	0.0121[j]	0.0086[j]	0.004[h]	0.029[j]	0.23[j]		
	0.047[i]	0.058[i]	0.081[i]	0.038[i]	0.047[i]			
Cucumber	0.34[g]							
Eggplant	0.19[g]	0.09[a]	0.001[d]	0.014[f]	0.0021[e]	0.0034[e]	0.0026[e]	
Garlic	0.02[g]	0.05[a]						
Lettuce	0.0101[k]	0.0087[k]	0.0074[k]	0.0016[k]	0.0054[k]	0.0041[k]		
	0.0014[k]	0.0002[k]	0.001[k]	0.0006[k]	0.0011[k]	0.0003[k]		
	0.00467[k]	0.00071[k]	0.00145[k]	0.00127[k]	0.00467[k]	0.00071[k]		
	0.06[g]	0.2[b]	0.05[f]	0.11[f]	0.06[g]	0.2[b]		
Okra	0.36[g]	0.09[a]	0.001[f]					
Onion	0.07[g]	0.048[a]						
Potato	0.09[g]	0.058[a]	0.006[f]	0.0002[k]	0.0006[k]	0.0001[k]	0.0002[k]	0.46[f]
Radish	0.04[g]	0.024[a]	0.001[d]	0.0008[e]	0.0013[e]	0.0009[e]		
	0.02[f]	0.05[f]	0.01279[k]	0.01003[k]	0.01043[k]	0.00063[k]		
Spinach	0.077[a]	0.0053[e]	0.0085[e]	0.0065[e]	0.0007[k]	0.0006[k]	0.0006[k]	0.00009[k]
Sunflower	0.003[h]							
Tomato	0.1[g]	0.019[a]	0.001[d]	0.0057[e]	0.0092[e]	0.007[e]		
Wheat	0.088[a]	0.0067[c]	0.0068[c]	0.014[c]	0.021[c]			
	0.029[c]	0.04[c]	0.0295[c]	0.03[c]	0.022[c]			
	0.012[c]	0.008[c]	0.028[c]	0.024[c]	0.009[c]			
	0.025[c]	0.04[c]	0.041[c]	0.036[c]				

[a] Alam et al. (2016)

[b] Antoniadis et al. (2016)

[c] Dai et al. (2016)

[d] Jolly et al. (2013)

[e] Kar et al. (2013)

[f] Khan et al. (2015)

[g] Rehman et al. (2016)

[h] Neidhardt et al. (2012)

[i] calculated from Rosas-Castor et al. (2014)

[j] calculated from Rosas-Castor et al. (2014)

[k] Warren et al. (2003)

Table 4.5. Background concentrations of arsenic in the edible plants, µg/kg

Bean	310[c]	200[c]	250[c]	490[c]	50[b]	48[b]	5[b]	223[b]	
Broccoli	2.1[a]	13.7[a]	6[a]	2.3[a]	3[a]	3.6[a]	4.4[a]	3.8[a]	2.6[a]
	2.7[a]	2.6[a]	7.3[a]	219.5[a]	38.5[a]	24.6[a]	17.3[a]	120.9[a]	
Cabbage	8.6[a]	5.8[a]	2.1[a]	3.1[a]	4.2[a]	7[a]	5.1[a]	3.2[a]	5.3[a]
	5.6[a]	3.9[a]	3.6[a]	3.2[a]	3.4[a]	5.3[a]	7.3[a]	4.5[a]	2.5[a]
	2.7[a]	4.6[a]	8.2[a]	8.4[a]	6.3[a]	2.8[a]	4.4[a]	2.1[a]	4.2[a]
	7.7[a]	2.1[a]	50.4[a]	79.4[a]	1.2[f]	16[f]	6[b]	4[b]	9[b]
Carrot	4.4[a]	3[a]	7.1[a]	4.8[a]	5.8[a]	6.1[a]	3.8[a]	13.3[a]	22.9[a]
	3.6[a]	5.5[a]	4.5[a]	16.8[a]	3.1[a]	6[a]	3.6[a]	2.1[a]	2.5[a]
	9[a]	13.7[a]	6.8[a]	22.9[a]	3.9[a]	4[a]	4[a]	5[a]	8.6[a]
	5.8[a]	4.7[a]	4.7[a]	41[a]	4.4[a]	2.7[a]	2[a]	2[a]	6.4[a]
	4.4[a]	5.6[a]	6.3[a]	2.2[a]	3.6[a]	16.5[a]	4[a]	4.8[f]	13[f]
	7[b]	290[c]	490[c]	8[b]	220[c]	5[b]	170[c]		
Cauliflower	2.6[a]	13.5[a]	2.3[a]	4.7[a]	3.2[a]	5.9[a]	3.3[a]	6.3[a]	2.5[a]
	2.9[a]	2[a]	4.4[a]	2.9[a]	4.5[a]	3.7[a]	2.4[a]	3.7[a]	3.4[a]
	2.2[a]	3.7[a]	5.6[a]	6.7[a]	4.2[a]	3.2[a]	6.7[a]	2.1[a]	12.3[a]
	17.6[a]								
Corn	25[f]								
Cucumber	16.5[a]	36.7[a]	4.2[a]	3.4[a]	28.9[a]	39.7[a]	69.1[a]		
Eggplant	80[e]	250[c]	180[c]	160[c]	410[c]				
Garlic	13[b]	8[b]	20[b]						
Lettuce	43.6[a]	2.1[a]	4.5[a]	100.3[a]	3.7[a]	4[a]	2.3[a]	6.1[a]	2.5[a]
	3.1[a]	8.2[a]	6.9[a]	3.1[a]	101.9[a]	5.8[a]	15.8[a]	59.7[a]	7.2[a]
	12.3[a]	5.6[a]	2.3[a]	8.7[a]	10.3[a]	8.5[a]	10.4[a]	5.3[f]	15[b]
	7[b]	31[b]							
Okra	51[e]								
Onion	5.8[a]	4.6[a]	8.7[a]	11.3[a]	5.8[a]	6.8[a]	18.7[a]	11[a]	6.4[a]

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Table 4.5. (Cont.)

Onion	2.5[a]	4.5[f]	280[c]	170[c]	230[c]	440[c]			
Potato	2.1[a]	2.5[a]	2.7[a]	3.3[a]	6.6[a]	5.4[a]	2.4[a]	2.9[a]	4.2[a]
	5.2[a]	4.5[a]	2[a]	4.5[a]	3.4[a]	7.4[a]	6.7[a]	4.8[a]	10.3[a]
	8.1[a]	6[a]	3.5[a]	2.1[a]	4.2[a]	8.5[a]	3.8[a]	4.2[a]	6[a]
	4.8[a]	10.1[a]	3.6[a]	4[a]	12.7[a]	2.7[a]	7.6[a]	6.9[a]	4.1[a]
	3.9[a]	2.6[a]	10.8[a]	4.8[a]	5[a]	7.1[a]	5.9[a]	4.6[a]	3.7[a]
	3.2[a]	3.9[a]	2.5[a]	3.72[a]	2.9[a]	2.4[a]	3.5[a]	2.8[a]	3[a]
	3.3[a]	2.8[a]	2.4[a]	2.4[a]	6.4[a]	12.7[a]	6.1[a]	19.6[a]	4.2[a]
	14.4[a]	10.6[a]	10.4[a]	5[a]	4[a]	2.3[a]	4.1[a]	9[b]	9[b]
	10[b]	350[c]	220[c]	370[c]	460[c]				
Radish	45.7[a]	53.4[a]							
Spinach	14.7[a]	67.9[a]	11.1[a]	12.5[a]	12.8[a]	26.2[a]	69.9[a]	56.3[a]	15.7[a]
	3.5[a]	17.3[a]	85[e]						
Sunflower	69.1[d]								
Tomato	3.2[a]	2.6[a]	4.4[a]	2.5[a]	0.46[f]	5[b]	3[b]	8[b]	280[c]
	110[c]	520[c]	220[c]						
Wheat	280[c]	95[c]	330[c]	420[c]					

[a] Norton et al. (2012)

[b] Ciminelli et al. (2017)

[c] Ahmed et al. (2016)

[d] reference material, IPE sample 168, Wageningen University Environmental Sciences

[e] Baig and Kazi (2012)

[f] Kabata-Pendias and Pendias (2011)

Table 4.6. Root depths of the edible plant species

Scientific Name	**Common name**	**Minimum depth, cm**	**Maximum depth, cm**
Phaseolus Vulgaris L.	**Bean**	60.96[a]	91.44[a]
Brassica Oleracea Var. İtalica	**Broccoli**	45.72[a]	91.44[a]
Brassica Oleracea Var. Capitata F. Alba	**Cabbage**	30.48[a]	-
Daucus Carota	**Carrot**	45.72[a]	60.96[a]
Brassica Oleracea Var. Botrytis	**Cauliflower**	45.72[a]	91.44[a]
Zea Mays	**Corn**	45.72[a]	91.44[a]
Cucumis Sativus	**Cucumber**	91.44[a]	121.92[a]
Solanum Melongena	**Eggplant**	91.44[a]	121.92[a]
Allium Sativum	**Garlic**	30.48[a]	45.72[a]
Lactuca Sativa	**Lettuce**	45.72[a]	-
Abelmoschus Esculentus	**Okra**	-	36.5[c]
Allium Cepa	**Onion**	20.32[a]	30.48[a]
Solanum Tuberosum	**Potato**	45.72[a]	60.96[a]
Raphanus Sativus L	**Radish**	12.7[a]	20.32[a]

(Cont. on next page)

Table 4.6. (Cont.)

Spinacia Oleracea	**Spinach**	30.48[a]	45.72[a]
Helianthus Annuus	**Sunflower (seed)**	-	270[b]
Lycopersicon Esculentum	**Tomato**	45.72[a]	121.92[a]
Triticum Aestivum	**Wheat**	-	300[b]

[a] University of California (2011)

[b] Canadell et al. (1996)

[c] Moyin-Jesu (2007), *maximum observed value for the study

4.9. Body Weights of Turkish People

TSI survey was the source of body weight data. TSI survey reports average body weights for different age groups and genders. Average values of male and female body weights reported in the survey were used since gender was not considered as a variable in this study. Table 4.7. shows average body weights of Turkish people in the recent years.

Table 4.7. Average body weights of Turkish people

	2008			**2010**			**2012**			**2014**		
Age group	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female
15-24	62.0	67.4	56.7	62.3	67.4	57.2	63.2	68.4	58.1	63.2	69.0	57.4
25-34	69.9	75.5	63.9	70.5	76.4	64.2	71.1	77.2	64.8	71.1	77.7	64.4
35-44	74.8	79.2	70.1	75.8	80.7	70.4	76.2	81.2	71.0	75.9	80.8	71.0
45-54	76.4	78.8	73.8	77.5	79.5	75.2	77.7	80.4	74.9	79.0	81.6	76.4
55-64	75.9	78.0	73.7	76.8	78.2	75.3	77.5	79.2	75.8	77.8	79.4	76.4
65-74	74.2	77.3	71.2	74.0	76.2	72.0	74.6	76.9	72.6	73.7	75.7	71.9
75+	67.5	72.3	63.6	68.6	71.2	65.9	69.1	72.2	66.7	69.1	73.3	66.3
Overall Average	**70.8**	**75.2**	**66.3**	**71.5**	**75.8**	**66.9**	**72.3**	**76.7**	**67.8**	**72.5**	**77.1**	**68.1**

4.10. Deterministic Approach for the Simav District

Three main “what-if exposure scenarios based on TSI agricultural data for the whole District of Simav” were created to assess arsenic risk for people of Simav by considering plant consumptions both from locally grown on contaminated land and other places with no contamination. For the first main scenario, it is assumed that people who live in Simav only consume plants produced in Simav as the worst case scenario. The second main scenario is based on 50% consumption from the local sources and 50% from the other places. Third main scenario assumes that people of Simav supply the subject foodstuff 90% from the other places, while local sources comprise the remaining 10%. Therefore FI_z values used in Equation 4.1 were 100%, 50%, and 10%, respectively for the 1^{st}, 2^{nd}, and 3^{rd} scenarios. Average of the literature reported background arsenic concentrations in the plants were used in the equation for uncontaminated food sources.

Kabata-Pendias and Pendias (2001) states that arsenic concentrations higher than the range of 5 to 20 mg/kg are toxic to the plants. Growth reduction, leaf wilting, violet coloration, root discoloration, and cell plasmolysis are the most common effects of arsenic toxicity (Kabata-Pendias and Pendias, 2011, p.359). Thus, arsenic concentrations larger than 5 mg/kg in the plants were assumed as 5 mg/kg in all scenarios.

Three sub-scenarios (upper-bound, central tendency and lower-bound estimations) under every main scenario were composed to reflect the variation in model variables. Upper-bound estimation is an estimate of the plausible upper limit which is not likely to be lower than the true risk value (Asante-Duah, 2002, p.324). For the upper-bound estimations 90th percentile values of the bioconcentration factors, consumption rates, soil and plant concentrations and 10th percentile value of the body weight were used. Central tendency estimations express most likely values compared to true risk values. 50th percentile values of the consumption rates, body weights, bioconcentration factors, soil arsenic concentrations and plant arsenic concentrations were used for central tendency scenarios in this study. For the lower-bound estimations 10th percentile values of the bioconcentration factors, consumption rates, soil and plant concentrations and 90th percentile value of the body weight chart were used. Details of the sub-scenarios are given in the below sections.

4.10.1. Upper-Bound Estimations

Ninetieth percentile values of consumption rates, bioconcentration factors and soil concentrations were used to create this scenario. Because body weight is in the denominator of Eq. 4.1, 10th percentile value was used for upper-bound estimation sub-scenarios. The upper-bound scenario represents plausible exposure at the high end of the range. Arsenic concentrations of the edible parts of the plants were calculated by using Equation 4.5. For the calculation of carcinogenic risk, exposure duration was considered as 74 years (90th percentile of the lifetime expectancy). Body weight was assumed as 63.2 kg (10th percentile of the body weight chart). Values which were used in the upper-bound scenarios are given below in the table 4.8.

4.10.2. Central Tendency Estimations

Fiftieth percentile values of the consumption rates, bioconcentration factors, body weights and soil arsenic concentrations were used to create central tendency scenario. Exposure frequency was assumed as 350 days/year. Exposure duration was accepted as 63 years (50th percentile of the lifetime expectancy) for carcinogenic risk calculation. Body weight was accepted as 74.1 kg (50th percentile of the body weight chart). Values that used in central tendency scenarios are given in the Table 4.9.

4.10.3. Lower-Bound Estimations

Tenth percentile values of consumption rates, bioconcentration factors, body weights, and soil concentrations were used to form this scenario. For the calculation of carcinogenic risk, exposure duration was considered as 49 years (10th percentile of the lifetime expectancy). Body weight was accepted as 77.6 kg (90th percentile value of the body weight chart). Values that used in lower-bound scenarios are given in the Table 4.10.

4.11. Probabilistic Approach for the Simav District

Monte-Carlo simulation (MCS) was used for implementation of probabilistic risk assessment of the Simav District. MCS assigns probability distributions to random variables in a model to include their uncertainty. The random variables in the equation 4.1, i.e. bioconcentration factors, consumption rates, soil concentrations, background As concentrations and exposure durations were fitted with a probability distribution. The best fitting distribution was selected based on Anderson-Darling, Kolmogorov-Smirnov and chi-square tests. Anderson-Darling test weighs differences between two distributions’ tails. Unlike the Anderson-Darling, Kolmogorov-Smirnov test focuses on differences in the medians of the distributions more than their tails. Chi-square compares squares of the observed and expected frequencies. Randomly selected 10,000 values for each random variable based on their fitted probability distributions.

Consumption ratio of the edible plants grown in the Simav District which ranged between 10% to 90% defined as a variable to consider every possibility in the population. Hazard quotient and risk values were defined as forecast values and simulation were run for 10,000 trials. Randomly selected 10,000 values for each random variable based on their fitted probability distributions are used to calculate the output variable of the model, exposure and risk in this study, creating 10,000 estimations to represent almost all possible scenarios. A fitted probability distribution, therefore, could be assumed as the distribution of the subject population.

4.12. A Scenario for only the Simav Plain

A more realistic scenario based on agricultural data for only the Simav Plain obtained through personal communication from the local governmental agricultural authority was created. Purpose of this scenario is to understand the health risks created by the crops actually growing on the Simav Plain. According to the local governmental agricultural authority, only five species among the chosen eighteen species are cultivated in the Simav Plain. *Phaseolus Vulgaris L.* (Bean), *Allium Sativum* (Garlic), *Zea Mays* (Corn), *Helianthus Annuus* (Sunflower), *Triticum Aestivum* (Wheat) are the species that are grown in the plain. In this scenario both deterministic and probabilistic approach were used to estimate individual and population-based health risks.

4.12.1. Deterministic Approach for the Simav Plain

In the deterministic-realistic scenario of the Simav Plain 50% consumption from the local sources and 50% from the other places was assumed. For the scenario, all data were examined with Grubb’s outlier test and detected outliers were removed. Fiftieth percentile values of the consumption rates, bioconcentration factors, body weights, and soil arsenic concentrations were used to create deterministic-realistic scenario for the Simav Plain. Exposure frequency was assumed as 350 days/year. Exposure duration was assumed as 53 years for carcinogenic risk calculation. Body weight was assumed as 74.1 kg (50th percentile of the body weight). Values that were used in the scenario are given in Table 4.11.

4.12.2. Probabilistic Approach for the Simav Plain

Monte-Carlo simulation was used for implementation of probabilistic risk assessment of the Simav Plain. For the probabilistic-realistic approach, all data were examined with Grubb’s outlier test and detected outliers were removed. Subsequently, the random variables in Equation 4.1, i.e. bioconcentration factor, consumption rate, soil concentration, background As concentration, and exposure duration, were fitted with a probability distribution. Consumption ratio of the edible plants grown in the Simav Plain, which ranged between 5% to 95%, defined as a variable to consider every possibility in the population. Hazard quotient and risk values were defined as forecast values and simulation were run for 10,000 trials. Randomly selected 10,000 values for each random variable based on their fitted probability distributions are used to calculate the output variable of the model, exposure and risk in this study, creating 10,000 estimations to represent almost all possible scenarios.

Table 4.8. Data used for the calculation of the upper-bound estimates

Plants	**BCF**	**Soil As Concentrations, mg/kg**	**Plant As Concentrations, mg/kg**	**Background As Concentrations, mg/kg**	**Consumption rates, g/day**	**Bioavailability**
Corn	0.058000	66.76	3.87	0.025	58.5	1.00
Lettuce	0.065000	66.76	4.34	0.017	14.5	0.50
Wheat	0.040200	71.72	2.88	0.281	626	1.00
Radish	0.038400	66.76	2.56	0.050	6.07	0.77
Potato	0.201000	66.76	5.00	0.023	175	1.00
Spinach	0.029050	66.76	1.94	0.033	7.67	1.00
Eggplant	0.130000	71.72	5.00	0.216	33.5	1.00
Cauliflower	0.015500	66.76	1.03	0.005	1.90	1.00
Cabbage	0.190000	66.76	5.00	0.008	22.3	1.00
Tomato	0.059500	71.72	4.27	0.097	327	1.00
Broccoli	0.001224	66.76	0.08	0.028	6.00	1.00
Okra	0.306000	66.76	5.00	0.051	1.29	1.00
Carrot	0.030000	66.76	2.00	0.029	19.9	0.98
Onion	0.067800	66.76	4.53	0.080	70.6	1.00
Garlic	0.047000	66.76	3.14	0.014	2.50	1.00
Cucumber	0.340000	71.72	5.00	0.028	58.6	1.00
Sunflower	0.003000	71.72	0.22	0.069	91.3	1.00
Bean	0.150000	66.76	5.00	0.197	9.00	1.00

Table 4.9. Data used for the calculation of central tendency scenario

Plants	BCF	Soil As Concentrations, mg/kg	Plant As Concentrations, mg/kg	Background As concentrations in plant, mg/kg	Consumption rates, g/day	Bioavailability
Corn	0.006100	53.0	0.323	0.025	47.3	1.00
Lettuce	0.002870	53.0	0.152	0.017	13.6	0.50
Wheat	0.025000	44.4	1.110	0.281	586	1.00
Radish	0.010230	53.0	0.542	0.050	5.59	0.77
Potato	0.003275	53.0	0.174	0.023	145	1.00
Spinach	0.002980	53.0	0.158	0.033	7.31	1.00
Eggplant	0.003400	44.4	0.151	0.216	27.6	1.00
Cauliflower	0.000845	53.0	0.045	0.005	1.90	1.00
Cabbage	0.011450	53.0	0.607	0.008	21.5	1.00
Tomato	0.008100	44.4	0.360	0.097	310	1.00
Broccoli	0.001195	53.0	0.063	0.028	6.00	1.00
Okra	0.090000	53.0	4.770	0.051	1.21	1.00
Carrot	0.030000	53.0	1.590	0.029	16.1	0.98
Onion	0.059000	53.0	3.127	0.080	60.5	1.00
Garlic	0.035000	53.0	1.855	0.014	2.34	1.00
Cucumber	0.340000	44.4	5.000	0.028	52.3	1.00
Sunflower	0.003000	44.4	0.133	0.069	78.2	1.00
Bean	0.150000	53.0	5.000	0.197	8.16	1.00

Table 4.10. Data used for the calculation of lower-bound estimations

Plants	BCF	Soil As Concentrations, mg/kg	Plant As Concentrations, mg/kg	Background As concentrations in plants, mg/kg	Consumption Rates, g/day	Bioavailability
Corn	0.000700	30.76	0.022	0.025	40.2	1.00
Lettuce	0.000576	30.76	0.018	0.017	11.9	0.50
Wheat	0.007760	25.42	0.197	0.281	553	1.00
Radish	0.000810	30.76	0.025	0.050	5.08	0.77
Potato	0.000138	30.76	0.004	0.023	133	1.00
Spinach	0.000440	30.76	0.014	0.033	6.81	1.00
Eggplant	0.001660	25.42	0.042	0.216	25.4	1.00
Cauliflower	0.000305	30.76	0.009	0.005	1.90	1.00
Cabbage	0.002000	30.76	0.062	0.008	19.8	1.00
Tomato	0.003350	25.42	0.085	0.097	290	1.00
Broccoli	0.000529	30.76	0.016	0.028	6.00	1.00
Okra	0.018800	30.76	0.578	0.051	1.04	1.00
Carrot	0.006800	30.76	0.209	0.029	7.35	0.98
Onion	0.050200	30.76	1.544	0.080	53.9	1.00
Garlic	0.023000	30.76	0.707	0.014	2.16	1.00
Cucumber	0.340000	25.42	5.000	0.028	50.7	1.00
Sunflower	0.003000	25.42	0.076	0.069	47.6	1.00
Bean	0.150000	30.76	4.614	0.197	7.76	1.00

Table 4.11. Data used for the deterministic-realistic approach

Plants	**BCF**	**Soil As Concentrations, mg/kg**	**Plant As Concentrations, mg/kg**	**Background As Concentrations, µg/kg**	**Consumption rates, g/day**	**Bioavailability**
Bean	0.15000	53.0	5.00	212	8.16	1
Corn	0.00535	53.0	0.28	25.0	47.2	1
Garlic	0.03500	53.0	1.86	13.0	2.34	1
Sunflower (seed)	0.00300	44.4	0.13	69.1	78.2	1
Wheat	0.02450	44.4	1.09	305	586	1

CHAPTER 5

RESULTS AND DISCUSSION

The results are discussed under two main sections: deterministic approach and probabilistic approach. In the deterministic aprroach, non-carcinogenic and carcinogenic risks were calculated by using point estimates of bioconcentration factors, consumption rates, background plant concentrations, soil arsenic concentrations, and exposure durations. In the probabilistic approach, an input distribution for every parameter was created in the Monte Carlo simulation and distributions of non-carcinogenic risks and carcinogenic risks were calculated.

5.1. Deterministic Approach for the Simav District

Three main scenarios and their sub-scenarios were formed due to consider different possibilities in terms of risk assessment and calculated point estimates of carcinogenic and non-carcinogenic risks for eighteen plant species are discussed in this section. The main scenarios were formed regarding fraction of consumptions from uncontaminated and contaminated areas. Sub-scenarios consider possibilities of exposure to arsenic via different consumption rates, soil arsenic concentrations, plants' arsenic concentrations, and body weights.

5.1.1. Scenario 1

This main scenario considers that people who live in Simav only consume edible plants produced in Simav. Upper-bound, central tendency, and lower-bound estimations under this main scenario are investigated in the below sections to cover the variation in the population.

5.1.1.1. Upper-Bound Estimation

Eighteen plant species were investigated in the manner of non-carcinogenic and carcinogenic risks. Upper-bound (90th percentile) values of consumption rates, bioconcentration factors, soil concentrations and lower-bound value of body weight (10th percentile) were used for the assessments in this scenario.

World Health Organization (WHO) recommended 15 µg/kg body weight for inorganic arsenic as provisional tolerable weekly intake (PTWI) for the assessment of dietary arsenic intake. However, this PTWI value has been withdrawn. Instead of withdrawn PTWI, a benchmark dose lower confidence limit (3 µg/kg-day) for a 0.5%

increased incidence of human lung cancer was suggested by JEFCA (JEFCA, 2010). In this study, 2.1 µg/kg-day which is calculated by dividing PTWI by seven were used as tolerable daily intake limit (TDI) because most of the risk assessments in the literature based on the PTWI. As seen in the Table 5.1, almost half of the plant species exceeded the tolerable daily intake limit. Chronic daily intake of arsenic from wheat and tomato were higher than 1000-folds of the tolerable daily intake limit. Lowest CDI value belonged to broccoli for both carcinogenic and non-carcinogenic risk assessment.

For non-carcinogenic risk, four plant species were found below concern limit (HQ<0.5). Lowest hazard quotient value was found for broccoli as 0.02. This result may be due to its bioconcentration factor and consumption rate. Broccoli is not consumed frequently and its consumption rate is 6 g/day. It also has a low bioconcentration factor (0.0012) which means transport of arsenic from soil to broccoli is very limited. The other three species under concern limit were cauliflower, okra, and garlic. Even though okra had the second highest bioconcentration factor in the upper-bound estimation, hazard quotient was still low due to its low consumption rate (1.29 g/day). This interpretation is also valid for garlic and cauliflower which have low consumption rates, 2.5 g/day and 1.9 g/day respectively. Hazard quotient values of lettuce, spinach, radish, carrot, and sunflower were greater than 0.5 and exceeded concern limit but did not reach significant risk level. Hazard quotient values of nine species reached and exceeded significant risk level of 2.0. Among these nine species, wheat had the highest hazard quotient value with 91.2. This value is a result of extensive consumption rate of wheat products in Turkey which is approximately 626 g/day. Second highest hazard quotient value belonged to tomato with 70.5. Tomatoes are also consumed extensively in Turkey (327 g/day). Tomato paste consumption in Turkey is approximately 9,672,023 kg/month which corresponds 4.09 g/day per capita (TSI, 2003). Four gram tomato paste nearly equals to twenty-four gram tomato. Namely, contribution of tomato paste to the total tomato consumption is quite low compared to fresh tomato consumption. Potato is also extensively consumed among Turkish people with a high consumption rate (175 g/day) and has a quite high hazard quotient value which is 44.2. Hazard quotient results showed that consumption rates of the plants provide the largest contribution to non-carcinogenic risk values.

Table 5.1. Risk assessment results of the upper-bound estimation of Scenario 1

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	3.44×10^{-3}	11.5	3.39×10^{-3}	5.09×10^{-3}
Lettuce	4.77×10^{-4}	1.59	4.70×10^{-4}	7.05×10^{-4}
Wheat	2.74×10^{-2}	91.2	2.70×10^{-2}	4.05×10^{-2}
Radish	1.82×10^{-4}	0.61	1.79×10^{-4}	2.69×10^{-4}
Potato	1.32×10^{-2}	44.2	1.31×10^{-2}	1.96×10^{-2}
Spinach	2.26×10^{-4}	0.75	2.23×10^{-4}	3.34×10^{-4}
Eggplant	2.54×10^{-3}	8.46	2.50×10^{-3}	3.76×10^{-3}
Cauliflower	2.98×10^{-5}	0.10	2.94×10^{-5}	4.41×10^{-5}
Cabbage	1.69×10^{-3}	5.65	1.67×10^{-3}	2.51×10^{-3}
Tomato	2.11×10^{-2}	70.5	2.09×10^{-2}	3.13×10^{-2}
Broccoli	7.44×10^{-6}	0.02	7.34×10^{-6}	1.10×10^{-5}
Okra	9.76×10^{-5}	0.33	9.63×10^{-5}	1.44×10^{-4}
Carrot	5.92×10^{-4}	1.97	5.84×10^{-4}	8.76×10^{-4}
Onion	4.85×10^{-3}	16.2	4.78×10^{-3}	7.17×10^{-3}
Garlic	1.19×10^{-4}	0.40	1.17×10^{-4}	1.76×10^{-4}
Cucumber	4.45×10^{-3}	14.8	4.39×10^{-3}	6.58×10^{-3}
Sunflower	2.98×10^{-4}	0.99	2.94×10^{-4}	4.41×10^{-4}
Bean	6.82×10^{-4}	2.28	6.73×10^{-4}	1.01×10^{-3}

5.1.1.2. Central Tendency Estimation

Fiftieth percentile values of consumption rates, soil concentrations, bioconcentration factors, and body weight were used to assess non-carcinogenic and carcinogenic risk.

Chronic daily intakes of four species exceeded the TDI limit. Wheat, tomato, onion and cucumber were the species which had highest CDI values. Among these, the highest CDI belonged to wheat while the lowest CDI belonged to cauliflower.

Hazard quotient values were found lower than the concern level for nine species which are lettuce, radish, spinach, eggplant, cauliflower, broccoli, okra, garlic, and sunflower. The lowest hazard quotient value was found for cauliflower as nearly equal to zero. As a result of reduction in the bioconcentration factors, soil concentrations and consumption rates, HQ values decreased significantly compared to the upper-bound estimation. Hazard quotient of eggplant decreased 47-folds by comparison to its values in upper-bound estimation. Significant reduction in HQs also was observed for wheat, cucumber, and tomato even though their HQ values were still high.

Table 5.2. Risk assessment Results of the Central Tendency Estimation of Scenario 1

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.98×10^{-4}	0.66	1.66×10^{-4}	2.49×10^{-4}
Lettuce	1.34×10^{-5}	0.05	1.12×10^{-5}	1.69×10^{-5}
Wheat	8.42×10^{-3}	28.1	7.07×10^{-3}	1.06×10^{-2}
Radish	3.02×10^{-5}	0.10	2.53×10^{-5}	3.80×10^{-5}
Potato	3.26×10^{-4}	1.09	2.74×10^{-4}	4.11×10^{-4}
Spinach	1.49×10^{-5}	0.05	1.25×10^{-5}	1.88×10^{-5}
Eggplant	5.38×10^{-5}	0.18	4.52×10^{-5}	6.78×10^{-5}
Cauliflower	1.10×10^{-6}	0.00	9.25×10^{-7}	1.39×10^{-6}
Cabbage	1.69×10^{-4}	0.56	1.42×10^{-4}	2.13×10^{-4}
Tomato	1.44×10^{-3}	4.80	1.21×10^{-3}	1.82×10^{-3}
Broccoli	4.92×10^{-6}	0.02	4.13×10^{-6}	6.19×10^{-6}
Okra	7.44×10^{-5}	0.25	6.25×10^{-5}	9.37×10^{-5}
Carrot	3.24×10^{-4}	1.08	2.72×10^{-4}	4.09×10^{-4}
Onion	2.45×10^{-3}	8.16	2.06×10^{-3}	3.08×10^{-3}
Garlic	5.61×10^{-5}	0.19	4.71×10^{-5}	7.07×10^{-5}
Cucumber	3.38×10^{-3}	11.3	2.84×10^{-3}	4.26×10^{-3}
Sunflower	1.35×10^{-4}	0.45	1.13×10^{-4}	1.70×10^{-4}
Bean	5.28×10^{-4}	1.76	4.43×10^{-4}	6.65×10^{-4}

Carcinogenic risk values also significantly decreased compared to the upper-bound estimation. However, plant species such as wheat, tomato, onion, corn, potato, cabbage, and cucumber remained in the significant risk zone. For the other species, carcinogenic risk stayed higher than the acceptable risk level ($>10^{-6}$). The lowest carcinogenic risk value belonged to cauliflower. Its risk value decreased approximately 10 times. This result may be due to its low arsenic concentration and low consumption rate. Results of the central tendency estimation can be seen in Table 5.2.

5.1.1.3. Lower-Bound Estimation

Tenth percentile values of consumption rates, bioconcentration factors and soil concentrations, and ninetieth percentile of the body weight were used to estimate lower-bound carcinogenic and non-carcinogenic risk levels.

Only three species among the plants exceeded significant non-carcinogenic risk level. All CDI values except cucumber’s stayed under the tolerable daily intake limit. Cucumber had the highest HQ value probably due to the limited bioconcentration factor data. Since there is only one bioconcentration value found for cucumber, arsenic concentration in cucumber remained same through the estimations. Even though the consumption rate and soil arsenic concentration reduced in lower-bound estimation for cucumber, HQ values did not change significantly and only decreased from 14 to 10. Wheat and onion are the other two species which represent significant non-carcinogenic risk for human health. Arsenic concentration in wheat decreased significantly from upper-bound estimation to lower-bound estimation, 2.88 mg/kg to 0.19 mg/kg, respectively. However, its consumption rate did not decrease to the same extent between the estimates, and stayed over 500 grams per day. Thus, HQ level of wheat decreased but stayed over the significant risk limit. Arsenic concentration in onion reduced 2-folds from upper-bound estimation to lower-bound estimation, and decreased 4.5 mg/kg to 1.5 mg/kg. Its consumption rate also decreased from 70 g/day to 53 g/day. As a result its HQ value declined from 16.2 to 3.43 but remained over the significant risk level. In addition to that three species, tomato and bean also exceeded the threshold limit with HQ values of 1.018 and 1.475, respectively. Other species stayed under the concern limit and most of them had HQ values around zero.

Table 5.3. Risk assessment Results of the Lower-bound Estimation of Scenario 1

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.07×10^{-5}	0.04	6.99×10^{-6}	1.05×10^{-5}
Lettuce	1.31×10^{-6}	0.00	8.54×10^{-7}	1.28×10^{-6}
Wheat	1.35×10^{-3}	4.50	8.82×10^{-4}	1.32×10^{-3}
Radish	1.20×10^{-6}	0.00	7.87×10^{-7}	1.18×10^{-6}
Potato	6.99×10^{-6}	0.02	4.56×10^{-6}	6.85×10^{-6}
Spinach	1.14×10^{-6}	0.00	7.45×10^{-7}	1.12×10^{-6}
Eggplant	1.32×10^{-5}	0.04	8.64×10^{-6}	1.30×10^{-5}
Cauliflower	2.20×10^{-7}	0.00	1.44×10^{-7}	2.16×10^{-7}
Cabbage	1.51×10^{-5}	0.05	9.83×10^{-6}	1.47×10^{-5}
Tomato	3.06×10^{-4}	1.02	2.00×10^{-4}	2.99×10^{-4}
Broccoli	1.21×10^{-6}	0.00	7.89×10^{-7}	1.18×10^{-6}
Okra	7.44×10^{-6}	0.03	4.86×10^{-6}	7.29×10^{-6}
Carrot	1.86×10^{-5}	0.06	1.22×10^{-5}	1.82×10^{-5}
Onion	1.03×10^{-3}	3.43	6.72×10^{-4}	1.01×10^{-3}
Garlic	1.89×10^{-5}	0.06	1.23×10^{-5}	1.85×10^{-5}
Cucumber	3.13×10^{-3}	10.4	2.05×10^{-3}	3.07×10^{-3}
Sunflower	4.49×10^{-5}	0.15	2.93×10^{-5}	4.40×10^{-5}
Bean	4.43×10^{-4}	1.48	2.89×10^{-4}	4.34×10^{-4}

All of the species except cauliflower exceeded the acceptable carcinogenic risk level (>10^{-6}). Cauliflower had the lowest CDI and carcinogenic risk in lower-bound estimation . Wheat, tomato, onion, cucumber, and bean reached the significant risk level. Among these four species, cucumber had the highest carcinogenic risk level due to its arsenic concentration. Wheat followed cucumber owing to its high consumption rate. Corn, eggplant, cabbage, carrot, and garlic did not reach the significant risk level but stayed within the considerable risk range. Table 5.3 shows risk assessment results of the lower-bound estimation.

5.1.2. Scenario 2

In this second main scenario, it was assumed that people in Simav consume 50% of their vegetables from Simav and 50% from external uncontaminated sources. Upper-bound, central tendency, and lower-bound estimations under this main scenario are presented in the below sections.

5.1.2.1. Upper-Bound Estimation

Ninetieth percentile values of consumption rates, soil As concentrations, and bioconcentration factors were used for the calculation of dietary arsenic intake from Simav plants. Average background concentrations of Arsenic in plants were used for the calculation of CDI from the external sources.

Eight of the species reached to the significant non-carcinogenic risk level and two species exceeded the threshold value. Wheat, potato, tomato, onion, and cucumber exceeded the tolerable daily intake value (2.1 µg/kg-day). The highest hazard quotient value belonged to wheat with 50. Background As concentration of wheat is 0.28 mg/kg, while As concentration in wheat from Simav is 2.88 mg/kg. Thus, compared to the first scenario’s upper-bound estimation there is a decline due to consumption from external sources. However its HQ value is extremely high compared to the other species. Generally, HQ values lessened almost 50% in comparison with the first scenario’s upper-bound estimation, which showed the importance of plant As concentrations.

The same interpretation is also valid for carcinogenic risk results. Risk values lessened almost 50% compared to the upper-bound estimation of the first scenario. Almost every specie exceeded the significant risk level except four. Garlic, okra, broccoli, and cauliflower remained under the significant risk level. Garlic and okra had very low background As concentrations compared to their As concentrations in the plain. Thus, risk levels decreased at least 10 times. Both broccoli and cauliflower had low consumption rates and background values, hence lower risk values. Results of the upper-bound estimaton can be seen in the Table 5.4.

Table 5.4. Risk assessment results of the upper-bound estimation of scenario 2

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.73×10^{-3}	5.77	1.71×10^{-3}	2.56×10^{-3}
Lettuce	2.39×10^{-4}	0.80	2.36×10^{-4}	3.54×10^{-4}
Wheat	1.50×10^{-2}	50.1	1.48×10^{-2}	2.22×10^{-2}
Radish	9.26×10^{-5}	0.31	9.14×10^{-5}	1.37×10^{-4}
Potato	6.65×10^{-3}	22.2	6.57×10^{-3}	9.85×10^{-3}
Spinach	1.15×10^{-4}	0.38	1.13×10^{-4}	1.70×10^{-4}
Eggplant	1.32×10^{-3}	4.41	1.31×10^{-3}	1.96×10^{-3}
Cauliflower	1.50×10^{-5}	0.05	1.48×10^{-5}	2.22×10^{-5}
Cabbage	8.49×10^{-4}	2.83	8.37×10^{-4}	1.26×10^{-3}
Tomato	1.08×10^{-2}	36.0	1.07×10^{-2}	1.60×10^{-2}
Broccoli	4.99×10^{-6}	0.02	4.92×10^{-6}	7.39×10^{-6}
Okra	4.93×10^{-5}	0.16	4.86×10^{-5}	7.30×10^{-5}
Carrot	3.00×10^{-4}	1.00	2.96×10^{-4}	4.45×10^{-4}
Onion	2.47×10^{-3}	8.22	2.43×10^{-3}	3.65×10^{-3}
Garlic	5.98×10^{-5}	0.20	5.90×10^{-5}	8.85×10^{-5}
Cucumber	2.24×10^{-3}	7.45	2.21×10^{-3}	3.31×10^{-3}
Sunflower	1.97×10^{-4}	0.66	1.94×10^{-4}	2.91×10^{-4}
Bean	3.55×10^{-4}	1.18	3.50×10^{-4}	5.25×10^{-4}

5.1.2.2. Central Tendency Estimation

Fiftieth percentile values of consumption rates, soil As concentrations, and bioconcentration factors were used for the calculation of dietary arsenic intake from edible plants. Average background concentrations of Arsenic in plants were used for the calculation of CDI from the external sources.

For non-carcinogenic risk, all CDI values except for wheat stayed under the TDI limit. Hazard quotients of wheat, tomato, onion, and cucumber exceeded the significant risk limit. Among them, wheat had the highest HQ value with 17.6. This value resulted from its high consumption rate which is 586 g/day. Other species stayed under the threshold limit. The lowest HQ was observed for cauliflower as 0.01. Generally, HQ values decreased approximately 40% in comparison with first scenario’s central tendency estimation. Only, HQ value for eggplant increased because its background As concentration was higher than the As concentration in contaminated plant.

Table 5.5. Risk assessment results of the central tendency estimation of scenario 2

Plants	Non-Carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.06×10^{-4}	0.36	8.94×10^{-5}	1.34×10^{-4}
Lettuce	7.45×10^{-6}	0.03	6.26×10^{-6}	9.39×10^{-6}
Wheat	5.28×10^{-3}	17.6	4.43×10^{-3}	6.65×10^{-3}
Radish	1.65×10^{-5}	0.06	1.38×10^{-5}	2.07×10^{-5}
Potato	1.85×10^{-4}	0.62	1.56×10^{-4}	2.33×10^{-4}
Spinach	9.02×10^{-6}	0.03	7.57×10^{-6}	1.14×10^{-5}
Eggplant	6.54×10^{-5}	0.22	5.50×10^{-5}	8.24×10^{-5}
Cauliflower	6.11×10^{-7}	0.00	5.13×10^{-7}	7.70×10^{-7}
Cabbage	8.56×10^{-5}	0.29	7.19×10^{-5}	1.08×10^{-4}
Tomato	9.14×10^{-4}	3.05	7.68×10^{-4}	1.15×10^{-3}
Broccoli	3.54×10^{-6}	0.01	2.98×10^{-6}	4.46×10^{-6}
Okra	3.76×10^{-5}	0.13	3.16×10^{-5}	4.74×10^{-5}
Carrot	1.65×10^{-4}	0.55	1.39×10^{-4}	2.08×10^{-4}
Onion	1.25×10^{-3}	4.18	1.05×10^{-3}	1.58×10^{-3}
Garlic	2.83×10^{-5}	0.09	2.37×10^{-5}	3.56×10^{-5}
Cucumber	1.70×10^{-3}	5.67	1.43×10^{-3}	2.14×10^{-3}
Sunflower	1.02×10^{-4}	0.34	8.59×10^{-5}	1.29×10^{-4}
Bean	2.74×10^{-4}	0.91	2.30×10^{-4}	3.46×10^{-4}

For carcinogenic risk assessment all CDI values except wheat stayed under the TDI limit. Most of the plant species exceeded the significant risk limit while others stayed in the considerable risk zone. Wheat had the highest carcinogenic risk and indicate significant risk for the human health while cauliflower had the lowest carcinogenic risk.

5.1.2.3. Lower-Bound Estimation

Tenth percentile values of consumption rates, bioconcentration factors and soil arsenic concentrations were used to estimate lower-bound risk in this scenario. For the body weight, 90th percentile value was used. Average background concentrations of arsenic in uncontaminated plants were used for the caluclation of CDI from external sources.

Non-carcinogenic risk assessment results can be seen in Table 5.6. There were only four species which exceeded the threshold risk level, and two of them also exceeded the significant non-carcinogenic risk level. Wheat and cucumber were the plants which had highest two HQ levels with 5.46 and 5.25, respectively. However, their CDI values did not exceed the TDI limit.

Table 5.6. Risk assessment results of the lower-bound estimation of scenario 2

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.16×10^{-5}	0.04	7.55×10^{-6}	1.13×10^{-5}
Lettuce	1.29×10^{-6}	0.00	8.40×10^{-7}	1.26×10^{-6}
Wheat	1.64×10^{-3}	5.46	1.07×10^{-3}	1.60×10^{-3}
Radish	1.80×10^{-6}	0.01	1.18×10^{-6}	1.76×10^{-6}
Potato	2.27×10^{-5}	0.08	1.48×10^{-5}	2.23×10^{-5}
Spinach	1.95×10^{-6}	0.01	1.27×10^{-6}	1.91×10^{-6}
Eggplant	4.05×10^{-5}	0.14	2.64×10^{-5}	3.96×10^{-5}
Cauliflower	1.68×10^{-7}	0.00	1.10×10^{-7}	1.65×10^{-7}
Cabbage	8.56×10^{-6}	0.03	5.59×10^{-6}	8.38×10^{-6}
Tomato	3.26×10^{-4}	1.09	2.13×10^{-4}	3.20×10^{-4}
Broccoli	1.64×10^{-6}	0.01	1.07×10^{-6}	1.61×10^{-6}
Okra	4.05×10^{-6}	0.01	2.64×10^{-6}	3.96×10^{-6}
Carrot	1.06×10^{-5}	0.04	6.93×10^{-6}	1.04×10^{-5}
Onion	5.41×10^{-4}	1.80	3.53×10^{-4}	5.30×10^{-4}
Garlic	9.61×10^{-6}	0.03	6.28×10^{-6}	9.42×10^{-6}
Cucumber	1.57×10^{-3}	5.25	1.03×10^{-3}	1.54×10^{-3}
Sunflower	4.28×10^{-5}	0.14	2.79×10^{-5}	4.19×10^{-5}
Bean	2.31×10^{-4}	0.77	1.51×10^{-4}	2.26×10^{-4}

Five species exceeded the significant risk level even though all carcinogenic CDI values remained under the TDI limit. Wheat, tomato, onion, cucumber, and bean are the plants with the most significant risk to human health in this estimation.

5.1.3. Scenario 3

In this third main scenario, it was assumed that people in Simav consume only 10% of their vegetables from Simav and 90% from uncontaminated external sources. Upper-bound, central tendency, and lower-bound estimations under this main scenario are presented in the below sections.

5.1.3.1. Upper-Bound Estimation

Ninetieth percentile values of consumption rates, soil As concentrations, and bioconcentration factors were used for the calculation of dietary arsenic intake from Simav plants. Average background concentrations of Arsenic in plants were used for the calculation of CDI from the external sources.

All CDI values except for tomato and wheat stayed under the TDI limit. Seven species exceeded the threshold value for non-carcinogenic risk. Among all the species wheat was the one that had the highest HQ value with 17.1 exceeding the significant risk limit. Tomato and potato also had high HQ values, and surpassed the significant risk level. Onion, corn, eggplant, and cucumber surpassed the threshold but stayed under the significant risk limit. Compared to the upper-bound estimation in the first scenario, HQ values decreased at least 60%. The most significant decline was in cabbage with almost 90%. In comparison with the upper-bound estimation in the second scenario, HQ values decreased at least 40% while the greatest decrease was in cabbage again.

For carcinogenic risk assessment, ten species exceeded the significant carcinogenic risk level. Among the species, wheat had the highest risk level while broccoli had the lowest. Only broccoli and cauliflower stayed under the considerable risk zone. Compared to the other upper-bound scenarios, risk values decreased at least 60% and 40% for the upper-bound estimation in the first scenario and for the upper-bound estimation in the second scenario, respectively. Cabbage was the plant variety that is observed with the highest decline while broccoli was the kind with the lowest decline. Risk assessment results can be seen in Table 5.7.

Table 5.7. Risk assessment results of the upper-bound estimation of Scenario 3

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	3.64×10^{-4}	1.21	3.59×10^{-4}	5.38×10^{-4}
Lettuce	4.93×10^{-5}	0.16	4.87×10^{-5}	7.30×10^{-5}
Wheat	5.14×10^{-3}	17.1	5.07×10^{-3}	7.61×10^{-3}
Radish	2.13×10^{-5}	0.07	2.11×10^{-5}	3.16×10^{-5}
Potato	1.38×10^{-3}	4.60	1.36×10^{-3}	2.04×10^{-3}
Spinach	2.60×10^{-5}	0.09	2.57×10^{-5}	3.85×10^{-5}
Eggplant	3.52×10^{-4}	1.18	3.48×10^{-4}	5.22×10^{-4}
Cauliflower	3.11×10^{-6}	0.01	3.07×10^{-6}	4.60×10^{-6}
Cabbage	1.72×10^{-4}	0.57	1.70×10^{-4}	2.55×10^{-4}
Tomato	2.55×10^{-3}	8.48	2.51×10^{-3}	3.77×10^{-3}
Broccoli	3.03×10^{-6}	0.01	2.99×10^{-6}	4.49×10^{-6}
Okra	1.07×10^{-5}	0.04	1.05×10^{-5}	1.58×10^{-5}
Carrot	6.70×10^{-5}	0.22	6.61×10^{-5}	9.91×10^{-5}
Onion	5.62×10^{-4}	1.87	5.55×10^{-4}	8.32×10^{-4}
Garlic	1.24×10-5	0.04	1.22×10^{-5}	1.83×10^{-5}
Cucumber	4.67×10-4	1.56	4.61×10^{-4}	6.92×10^{-4}
Sunflower	1.16×10-4	0.39	1.14×10^{-4}	1.72×10^{-4}
Bean	9.24×10-5	0.31	9.12×10^{-5}	1.37×10^{-4}

5.1.3.2. Central Tendency Estimation

Fiftieth percentile values of consumption rates, soil As concentrations, and bioconcentration factors were used for calculation of dietary arsenic intake from Simav plants. Average background concentrations of Arsenic in plants were used for the calculation of CDI from the external sources.

Four of the species exceeded the non-carcinogenic threshold value. Among them, wheat was the plant variety that had the greatest HQ value with 9.21. All CDI values except for wheat remained under the TDI limit. Corn, lettuce, radish, potato, spinach, eggplant, cauliflower, broccoli, cabbage, okra, carrot, garlic, sunflower, and bean stayed under the concern limit. Compared to the other central tendency estimations, HQ values decreased at least 30%. Only incline was observed in the eggplant. This result may be due to its background As concentration which is higher than the As concentration in the contaminated plant.

Most of the plant species remained under the significant carcinogenic risk limit while four species exceeded the limit. Wheat, tomato, onion, and cucumber were the species with the highest risk values. Compared to the other central tendency estimations at least 30% decline was observed for the plant species except eggplant. For eggplant, 27% incline was observed in comparison with central tendency estimation in the first scenario. This result arised due to its background As concentration which is higher than the As concentration in the contaminated plant from Simav.

Table 5.8. Risk assessment results of the central tendency estimation of Scenario 2

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	3.35×10^{-5}	0.11	2.82×10^{-5}	4.22×10^{-5}
Lettuce	2.70×10^{-6}	0.01	2.27×10^{-6}	3.40×10^{-6}
Wheat	2.76×10^{-3}	9.21	2.32×10^{-3}	3.48×10^{-3}
Radish	5.50×10^{-6}	0.02	4.62×10^{-6}	6.93×10^{-6}
Potato	7.22×10^{-5}	0.24	6.06×10^{-5}	9.09×10^{-5}
Spinach	4.28×10^{-6}	0.01	3.60×10^{-6}	5.39×10^{-6}
Eggplant	7.47×10^{-5}	0.25	6.28×10^{-5}	9.41×10^{-5}
Cauliflower	2.20×10^{-7}	0.00	1.84×10^{-7}	2.77×10^{-7}
Cabbage	1.90×10^{-5}	0.06	1.59×10^{-5}	2.39×10^{-5}
Tomato	4.92×10^{-4}	1.64	4.14×10^{-4}	6.20×10^{-4}
Broccoli	2.44×10^{-6}	0.01	2.05×10^{-6}	3.08×10^{-6}

(Cont. on next page)

Table 5.8. (Cont.)

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Okra	8.16×10^{-6}	0.03	6.85×10^{-6}	1.03×10^{-5}
Carrot	3.78×10^{-5}	0.13	3.18×10^{-5}	4.76×10^{-5}
Onion	3.01×10^{-4}	1.00	2.53×10^{-4}	3.80×10^{-4}
Garlic	5.98×10^{-6}	0.02	5.02×10^{-6}	7.54×10^{-6}
Cucumber	3.56×10^{-4}	1.18	2.99×10^{-4}	4.48×10^{-4}
Sunflower	7.64×10^{-5}	0.25	6.41×10^{-5}	9.62×10^{-5}
Bean	7.15×10^{-5}	0.24	6.01×10^{-5}	9.01×10^{-5}

5.1.3.3. Lower-Bound Estimation

Tenth percentile values of consumption rates, bioconcentration factors, and soil arsenic concentrations were used to estimate lower-bound risk in this scenario. For body weight, 90th percentile value was used. Average background concentrations of arsenic in uncontaminated plants were used for the calculation of CDI from external sources.

Only three species exceeded the non-carcinogenic threshold limit. Wheat was the only plant variety which exceeded the significant risk level with 6.22. Most of the species stayed under the concern level. Generally, HQ values showed decrease compared to the other lower-bound estimations for the majority of the plants. However, some of the plants such as wheat, tomato, potato, corn, eggplant, radish, and broccoli showed increase in the HQ values. This results probably because the average background As concentrations in plants was used in all scenarios since it could not be considered as a variable due to the data limitation. While arsenic concentrations in contaminated plants decreasing, background As concentrations stayed constant. Hence, for some plants As concentrations in contaminated plants remained lower compared to the uncontaminated plants.

For carcinogenic risk, four species exceeded the significant carcinogenic risk level. Cucumber, onion, tomato, and wheat were the species which had the highest risk levels. Only cauliflower stayed in the acceptable risk zone. For most of the species, a decrease was observed in comparison with the other lower-bound scenarios. However, for some species such as eggplant, potato, and spinach, an increase in the risk values was observed. For potato, almost 80% increase was observed compared to upper-bound estimation in the first scenario. This results may be due to the use of average arsenic background concentrations.

Table 5.9. Risk assessment results of the lower-bound estimation of scenario 3

Plants	Non-carcinogenic CDI, (mg/kg-day)	HQ	Carcinogenic CDI, (mg/kg-day)	Carcinogenic Risk
Corn	1.22×10^{-5}	0.04	8.00×10^{-6}	1.20×10^{-5}
Lettuce	1.27×10^{-6}	0.00	8.29×10^{-7}	1.24×10^{-6}
Wheat	1.87×10^{-3}	6.22	1.22×10^{-3}	1.83×10^{-3}
Radish	2.28×10^{-6}	0.01	1.49×10^{-6}	2.23×10^{-6}
Potato	3.53×10^{-5}	0.12	2.31×10^{-5}	3.46×10^{-5}
Spinach	2.60×10^{-6}	0.01	1.70×10^{-6}	2.54×10^{-6}
Eggplant	6.22×10^{-5}	0.21	4.07×10^{-5}	6.10×10^{-5}
Cauliflower	1.27×10^{-7}	0.00	8.27×10^{-8}	1.24×10^{-7}
Cabbage	3.36×10^{-6}	0.01	2.19×10^{-6}	3.29×10^{-6}
Tomato	3.42×10^{-4}	1.14	2.24×10^{-4}	3.36×10^{-4}
Broccoli	1.99×10^{-6}	0.01	1.30×10^{-6}	1.95×10^{-6}
Okra	1.33×10^{-6}	0.00	8.71×10^{-7}	1.31×10^{-6}
Carrot	4.20×10^{-6}	0.01	2.75×10^{-6}	4.12×10^{-6}
Onion	1.51×10^{-4}	0.50	9.87×10^{-5}	1.48×10^{-4}
Garlic	2.21×10^{-6}	0.01	1.45×10^{-6}	2.17×10^{-6}
Cucumber	3.29×10^{-4}	1.10	2.15×10^{-4}	3.23×10^{-4}
Sunflower	4.11×10^{-5}	0.14	2.68×10^{-5}	4.03×10^{-5}
Bean	6.13×10^{-5}	0.20	4.00×10^{-5}	6.00×10^{-5}

5.2. Probabilistic Approach for the Simav District

Non-carcinogenic and carcinogenic risks for every plant variety were calculated by using Monte Carlo Simulation. Bioconcentration factors, consumption rates, background As concentrations, exposure duration, fraction of plants ingested from contaminated source, and body weights were fitted a probability distribution. All input distributions can be seen in the Appendix A.

Body weight data were fitted a normal distribution to be used as an input distribution. The mean body weight and standard deviation were calculated as 72.26 kg and 4.79 kg, respectively. Exposure duration for carcinogenic risk assesments was fitted a uniform distribution. Minimum exposure duration was set as 30 years while maximum exposure was 75 years, the average life expectancy in Turkey (The World Bank, 2017). For all plant species, the same body weight and exposure duration input distributions were used. Two different soil arsenic concentration input distributions were used in the calculations. For the plants which have root depths less than 1 meter, only soil arsenic concentrations in 1meter depth were used and the best fitting distribution was logistic distribution. The minimum As concentration was 17.9 mg/kg and maximum was 92.5

mg/kg for the first meter of soil. The mean As concentration and standard deviation were calculated by the simulation as 48.9 and 18.4 mg/kg, respectively. For the plants which have root depths more than 1 meter, soil As concentrations in 1 to 5 meters depth were used, and the best fitting distribution was lognormal distribution. Minimum As concentration was 17.9 mg/kg while maximum was 113.1 mg/kg. The mean As concentration and standard deviation were calculated by the simulation as 46.2 and 21.4 mg/kg, respectively. Fraction of plants ingested from contaminated source was fitted a uniform distribution. The selection of the distribution was arbitrary due to the lack of data. Minimum fraction was entered as 0.10 while maximum fraction was entered as 0.9.

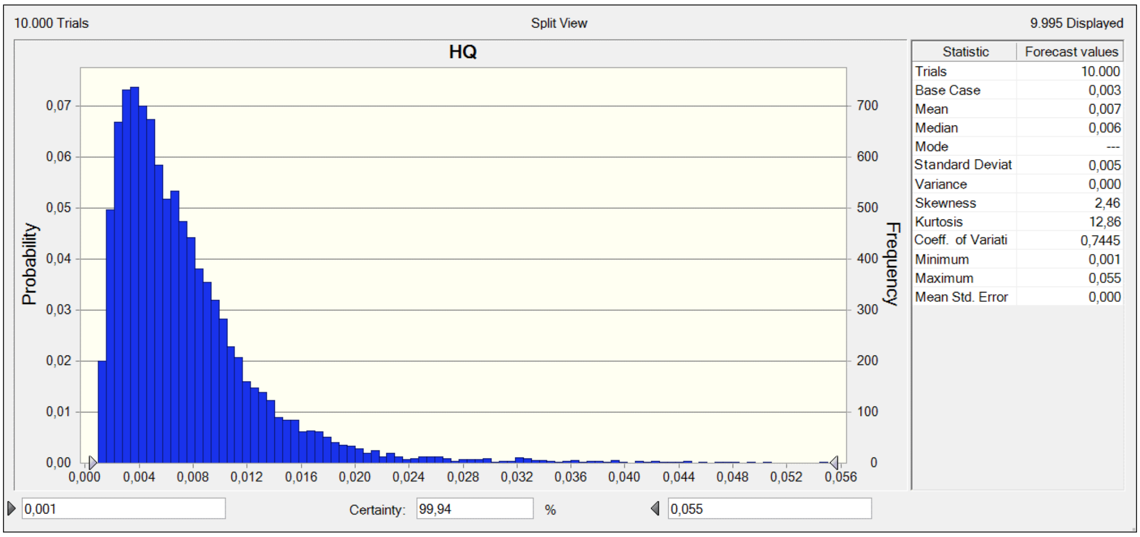
Bioconcentration factors, background As concentrations, and consumption rates were fitted with a distribution for each plant variety. Calculated non-carcinogenic and carcinogenic risk values are presented in the following sections.

5.2.1. Broccoli

Uniform distribution was the best fit to bioconcentration factor data of broccoli. Minimum BCF value was entered as 0.00025 while maximum was 0.00123. Background As concentrations in uncontaminated plants entered into simulation and was fit a pareto distribution. Minimum background arsenic concentration was 2 µg/kg while maximum was 220 µg/kg. Its location and shape was defined as 1.93 and 0.685, respectively. After defining the input parameters and distributions simulation was run for 10,000 times and the risk values were calculated.

5.2.1.1. Non-carcinogenic Risk Assessment of broccoli

The mean estimated HQ was 0.007. Maximum HQ was 0.0546 and minimum was 0.00077. None of the HQ values could not reach the concern limit. Skewness of the data was 2.46. Mass of the distribution concentrated on the left side of the graph which demonstrates that lower HQ values are more likely to occur. The frequency histogram and descriptive statistics are presented in Figure 5.1. Standard deviation was found as 0.0054.

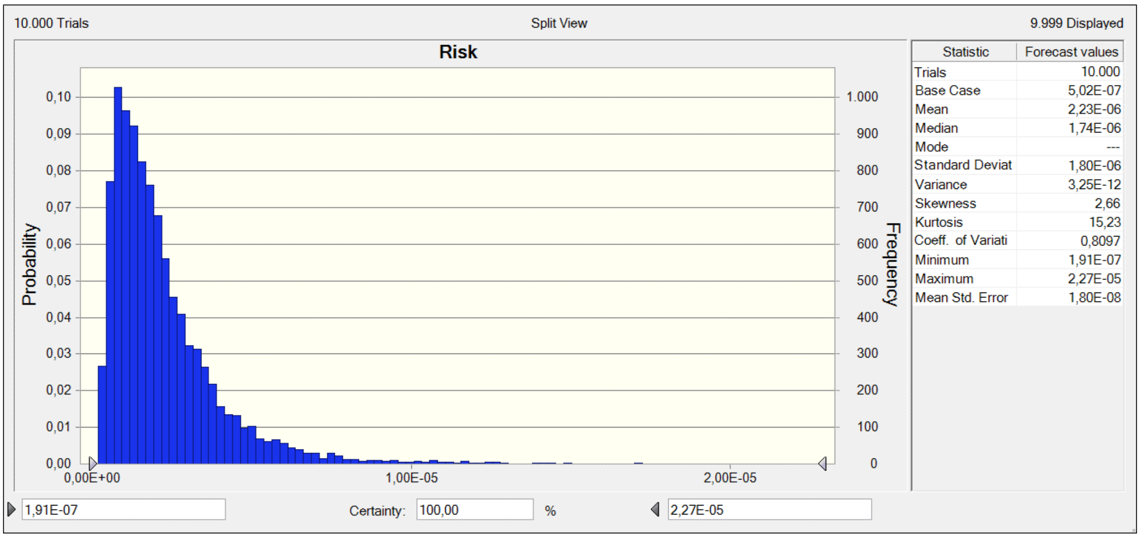


Statistic	Forecast values
Trials	10.000
Base Case	0,003
Mean	0,007
Median	0,006
Mode	---
Standard Deviat	0,005
Variance	0,000
Skewness	2,46
Kurtosis	12,86
Coeff. of Variati	0,7445
Minimum	0,001
Maximum	0,055
Mean Std. Error	0,000

Figure 5.1. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of broccoli

5.2.1.2. Carcinogenic Risk Assessment of broccoli

The mean estimated risk was 2.23×10^{-6} and exceeded acceptable risk level. Maximum risk value was 2.27×10^{-5} whilst minimum was 1.91×10^{-7}. Skewness value was found positive and showed that mass of the data concentrated on the left side of the graph. Hence, risk values lower than the mean risk are more likely to occur. Standard deviation was found as 1.80×10^{-6}. The frequency histogram and descriptive statistics are presented in the Figure 5.2.



Statistic	Forecast values
Trials	10.000
Base Case	5,02E-07
Mean	2,23E-06
Median	1,74E-06
Mode	---
Standard Deviat	1,80E-06
Variance	3,25E-12
Skewness	2,66
Kurtosis	15,23
Coeff. of Variati	0,8097
Minimum	1,91E-07
Maximum	2,27E-05
Mean Std. Error	1,80E-08

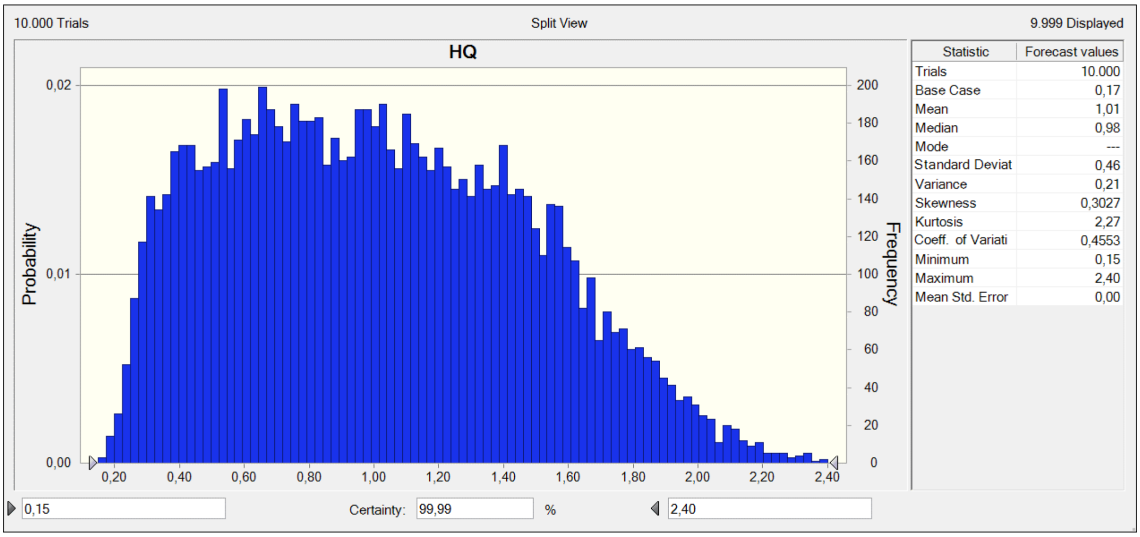
Figure 5.2. The frequency histogram and descriptive statistics of carcinogenic risk assessment of broccoli

5.2.2. Bean

Bioconcentration factor of the bean was entered into simulation as a single value (0.15) since there is no other data obtained about bioconcentration factor of the bean. Consumption rate of the bean was fit a uniform distribution. Minimum value was 6.45 g/day and maximum value was 10.52 g/day . Background arsenic concentrations were fit a uniform distribution. Minimum and maximum values of background arsenic concentrations were 5 and 490 µg/kg respectively.

5.2.2.1. Non-carcinogenic Risk Assessment of the Bean

Maximum and minimum hazard quotient values were found as 2.396 and 0.148 respectively. Mean HQ was found as 1.01 and exceeded threshold limit. Skewness was found as 0.3027. Skewness values close to zero represents equally scattered data to the graph. Thus, 0.3027 signifies little more concentrated on the left side of the graph but almost equally scattered data. Yet, HQ values lower than the mean HQ value are more likely to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.3.

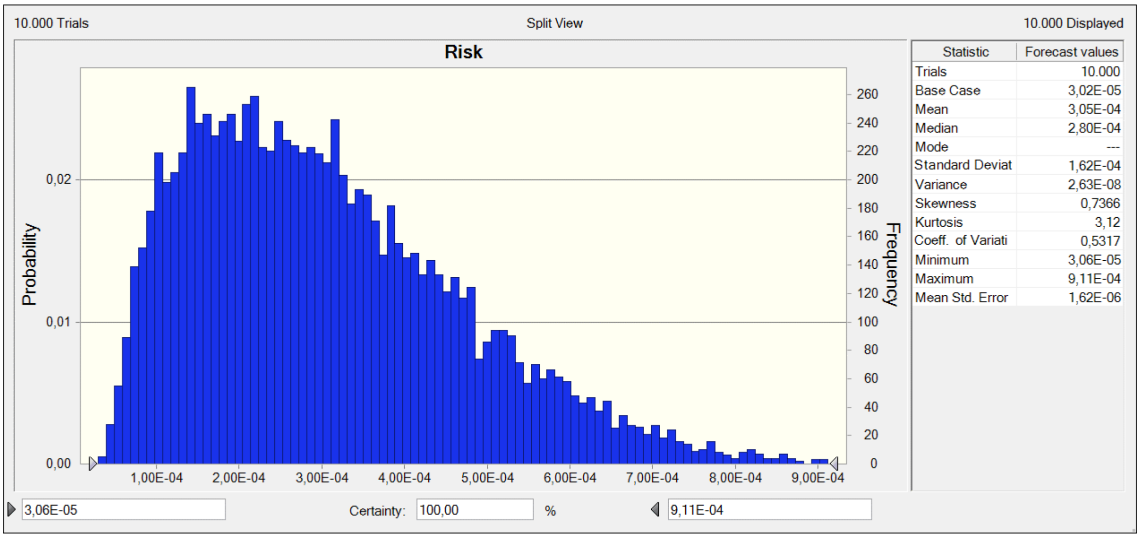


Statistic	Forecast values
Trials	10.000
Base Case	0,17
Mean	1,01
Median	0,98
Mode	---
Standard Deviat	0,46
Variance	0,21
Skewness	0,3027
Kurtosis	2,27
Coeff. of Variati	0,4553
Minimum	0,15
Maximum	2,40
Mean Std. Error	0,00

Figure 5.3. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the Bean

5.2.2.2. Carcinogenic Risk Assessment of the Bean

The mean carcinogenic risk value was found as 3.05×10^{-4} for bean and exceeded significant risk level. Maximum risk was 9.11×10^{-4} and minimum was 3.06×10^{-5}. All risk values exceeded the considerable risk limit. Data was skewed to right and risk values lower than the mean risk are more possible to occur. Standard deviation was found as 1.62×10^{-4}. The frequency histogram and descriptive statistics are presented in the Figure 5.4.



Statistic	Forecast values
Trials	10.000
Base Case	3,02E-05
Mean	3,05E-04
Median	2,80E-04
Mode	---
Standard Deviat	1,62E-04
Variance	2,63E-08
Skewness	0,7366
Kurtosis	3,12
Coeff. of Variati	0,5317
Minimum	3,06E-05
Maximum	9,11E-04
Mean Std. Error	1,62E-06

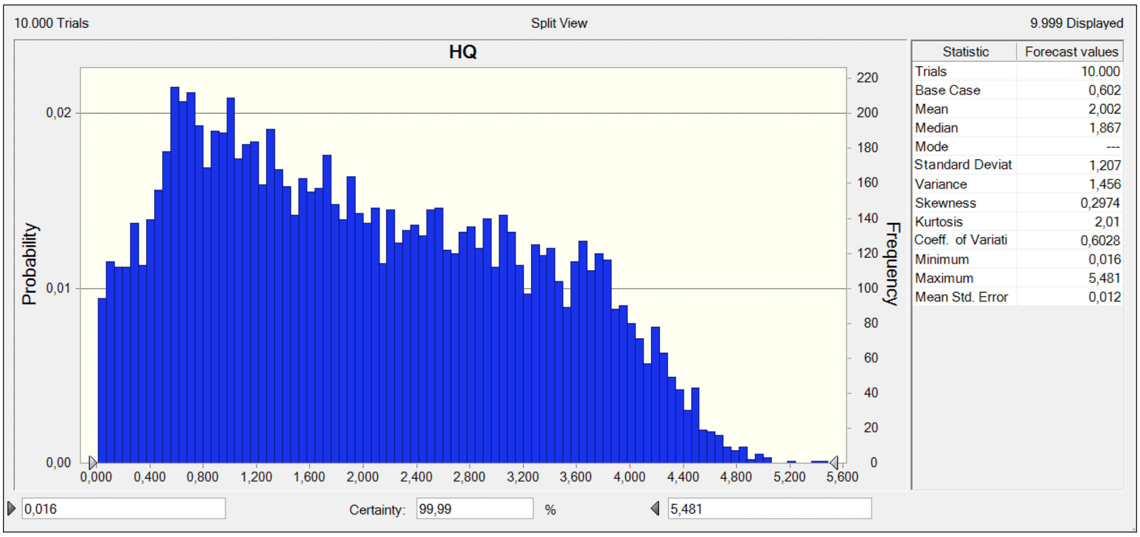
Figure 5.4. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the Bean

5.2.3. Cabbage

Bioconcentration factor data of cabbage was fit a uniform distribution. Minimum BCF was 0.0018 while maximum was 0.33. Consumption rate also was fit a uniform distribution between 19.06 and 22.42 g/day. Background arsenic concentrations of cabbage were fit as lognormal distribution. Minimum background arsenic concentration was 1.20 µg/kg whilst maximum was 79.40 µg/kg. Location, mean and standard deviation of the data were 0.91, 7.35 and 8.37 respectively.

5.2.3.1. Non-carcinogenic Risk Assessment of Cabbage

Mean HQ was found as 2.002 while minimum and maximum were 0.016 and 5.481 respectively. Skewness was found as 0.2974 and mass of the data was almost equally scattered on the graph. Standard deviation was found as 1.207. The frequency histogram and descriptive statistics are presented in the Figure 5.5.

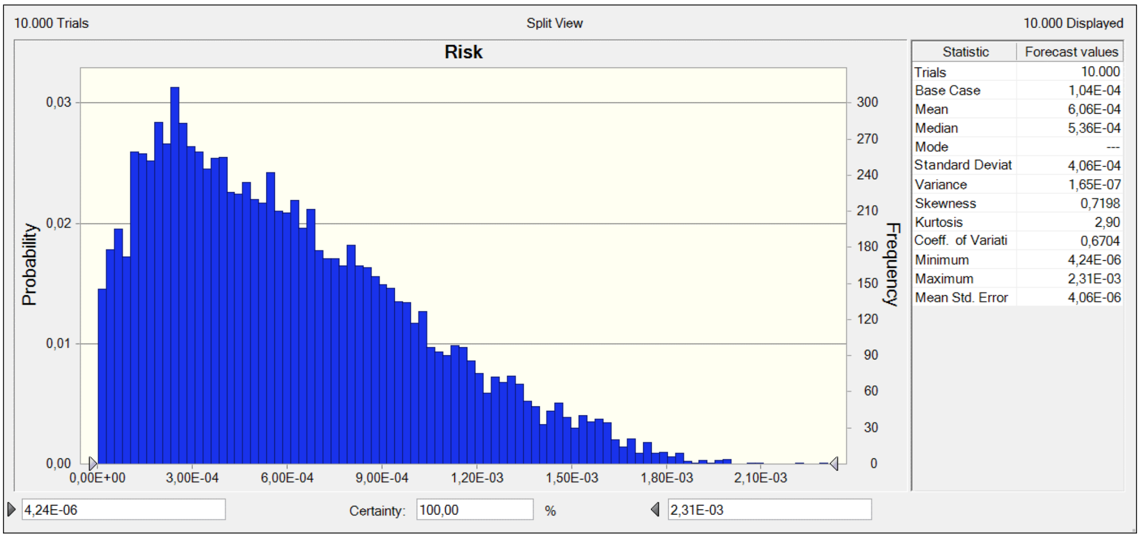


Statistic	Forecast values
Trials	10.000
Base Case	0,602
Mean	2,002
Median	1,867
Mode	---
Standard Deviat	1,207
Variance	1,456
Skewness	0,2974
Kurtosis	2,01
Coeff. of Variati	0,6028
Minimum	0,016
Maximum	5,481
Mean Std. Error	0,012

Figure 5.5. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of cabbage

5.2.3.2. Carcinogenic Risk Assessment of Cabbage

Mean risk was found as 6.06×10^{-4} while maximum and minimum were 2.31×10^{-3} and 4.24×10^{-6} respectively. All of the risk values were higher than the acceptable risk limit. Skewness was 0.7198 and signified that risk values lower than the mean risk are more likely to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.6.



Statistic	Forecast values
Trials	10.000
Base Case	1,04E-04
Mean	6,06E-04
Median	5,36E-04
Mode	---
Standard Deviat	4,06E-04
Variance	1,65E-07
Skewness	0,7198
Kurtosis	2,90
Coeff. of Variati	0,6704
Minimum	4,24E-06
Maximum	2,31E-03
Mean Std. Error	4,06E-06

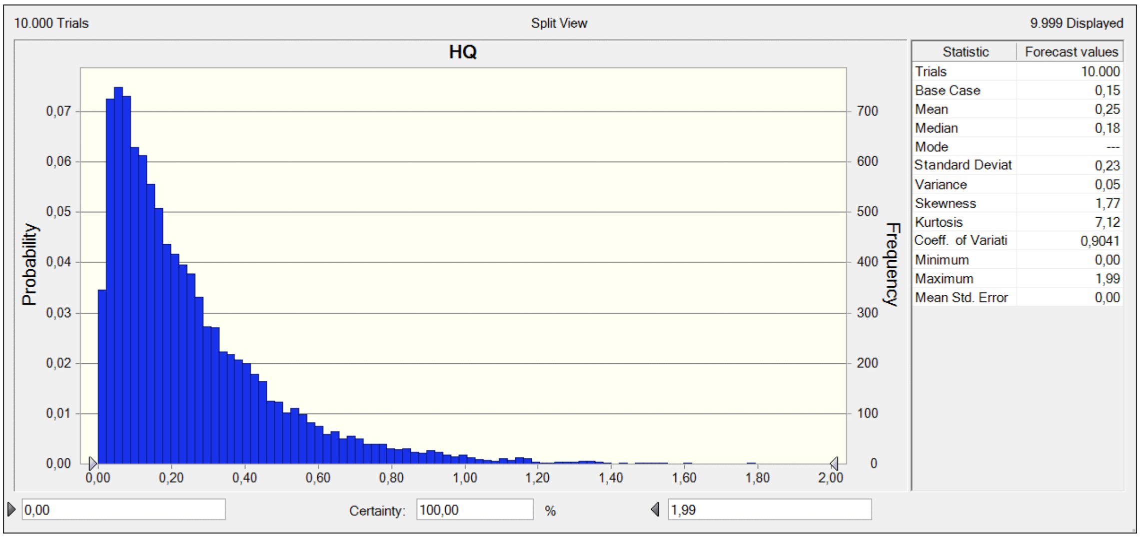
Figure 5.6. The frequency histogram and descriptive statistics of carcinogenic risk assessment of cabbage

5.2.4. Carrot

Bioconcentration factor of carrot was fit a uniform distribution. Maximum BCF was 0.03 while minimum was 0.001. Consumption rate was also fit a uniform distribution that between 6.62 g/day and 20.93 g/day. Background arsenic concentration data was fit a lognormal distribution which its location was 1.94 and standard deviation was 88.78. Mean background arsenic concentration was 20.94 µg/kg while minimum and maximum were 2 and 490 µg/kg respectively.

5.2.4.1. Non-carcinogenic Risk Assessment of Carrot

The mean hazard quotient was found as 0.249. Maximum HQ was 1.99 and exceeded threshold limit but did not represent significant risk. Minimum HQ was found as 0.0023 which nearly close to zero and did not reach the concern level. Skewness was found as 1.77. Thus, lower HQs than mean HQ value are more possible to be encountered. Standard deviation was found as 0.225. The frequency histogram and descriptive statistics are presented in the Figure 5.7.



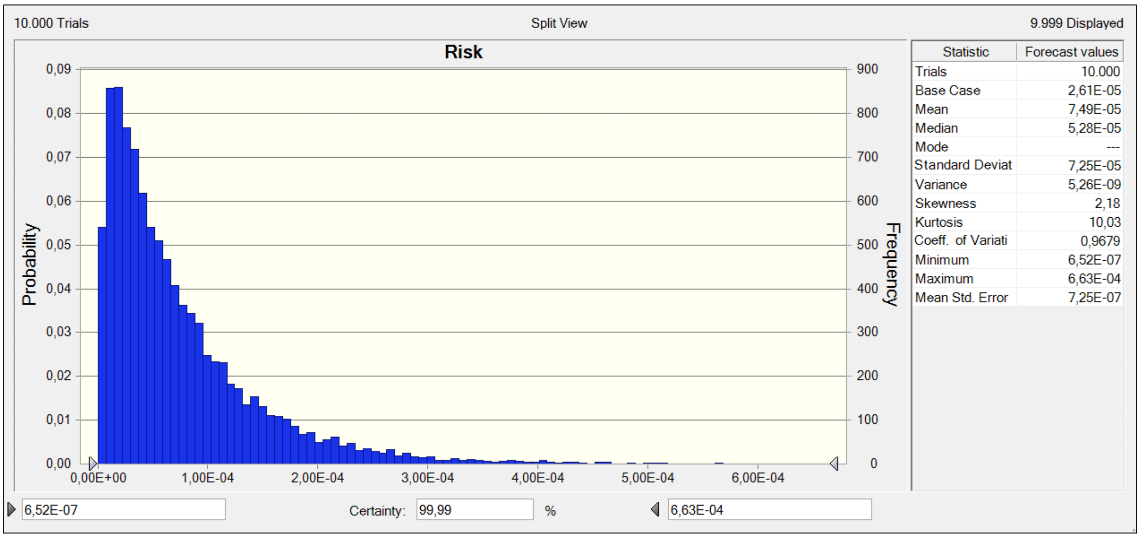
Statistic	Forecast values
Trials	10.000
Base Case	0,15
Mean	0,25
Median	0,18
Mode	---
Standard Deviat	0,23
Variance	0,05
Skewness	1,77
Kurtosis	7,12
Coeff. of Variati	0,9041
Minimum	0,00
Maximum	1,99
Mean Std. Error	0,00

Figure 5.7. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of carrot

5.2.4.2. Carcinogenic Risk Assessment of Carrot

The mean risk was found as 7.49×10^{-5} while minimum was 6.52×10^{-7} and maximum was 6.63×10^{-4}. Maximum risk value exceeded the significant risk limit. Skewness showed that risk values closer to the mean are more possible to occur.

Standard deviation was found as 7.25×10^{-5}. The frequency histogram and descriptive statistics are presented in the Figure 5.8.



10.000 Trials Split View 9.999 Displayed

Statistic	Forecast values
Trials	10.000
Base Case	2,61E-05
Mean	7,49E-05
Median	5,28E-05
Mode	---
Standard Deviat	7,25E-05
Variance	5,26E-09
Skewness	2,18
Kurtosis	10,03
Coeff. of Variati	0,9679
Minimum	6,52E-07
Maximum	6,63E-04
Mean Std. Error	7,25E-07

6,52E-07 Certainty: 99,99 % 6,63E-04

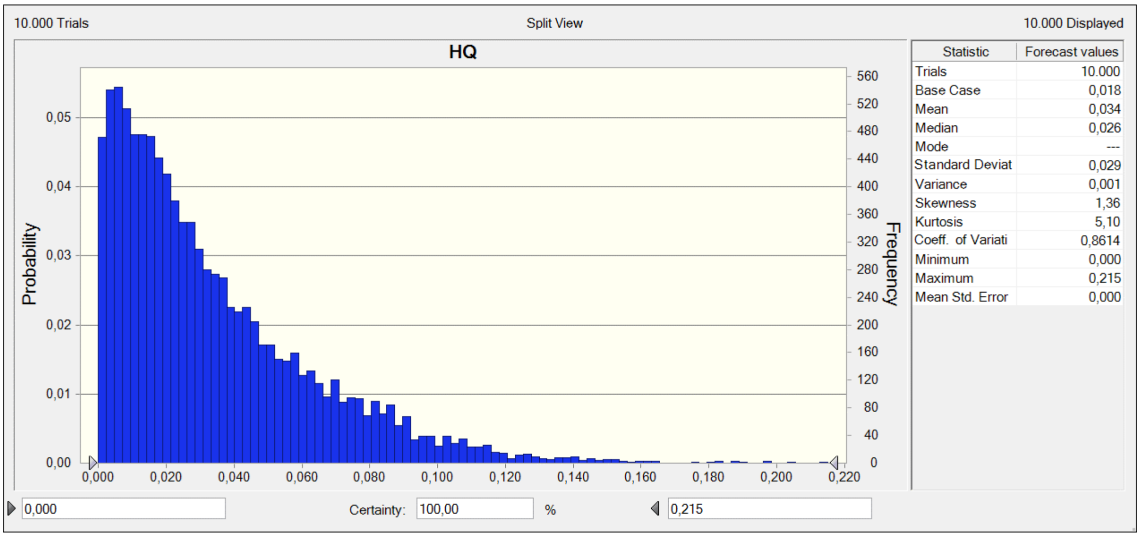
Figure 5.8. The frequency histogram and descriptive statistics of carcinogenic risk assessment of carrot

5.2.5. Cauliflower

Bioconcentration factor data was fit a uniform distribution which had 0.00011 as minimum and 0.03 as maximum. Consumption rate was entered as single value (1.9 g/day). Background arsenic concentrations was fit a lognormal distribution. Minimum value was 2 µg/kg and maximum value was 17.6 µg/kg while its location was 1.87. Mean background arsenic concentration was calculated as 5.19 µg/kg and standard deviation was 5.52 .

5.2.5.1. Non-carcinogenic Risk Assessment of Cauliflower

Maximum and minimum HQs was calculated as 0.0002 and 0.215 respectively. Mean HQ was 0.034 and standard deviation was 0.029. None of the HQ values did not exceed threshold limit. Skewness was 1.36 and showed that mass of the data was concentrated on the left side of the graph. The frequency histogram and descriptive statistics are presented in the Figure 5.9.



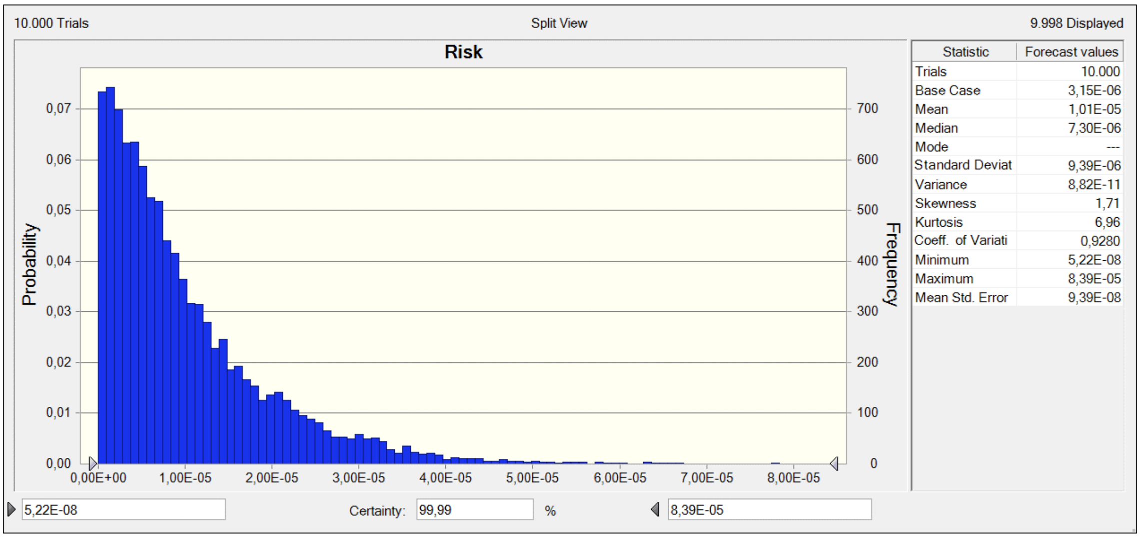
Statistic	Forecast values
Trials	10.000
Base Case	0,018
Mean	0,034
Median	0,026
Mode	---
Standard Deviat	0,029
Variance	0,001
Skewness	1,36
Kurtosis	5,10
Coeff. of Variati	0,8614
Minimum	0,000
Maximum	0,215
Mean Std. Error	0,000

0,000 Certainty: 100,00 % 0,215

Figure 5.9. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of cauliflower

5.2.5.2. Carcinogenic Risk Assessment of Cauliflower

Maximum risk value was 8.39×10^{-5} and exceeded considerable risk limit. Mean and minimum values were found as 1.01×10^{-5} and 5.22×10^{-8} respectively. Minimum risk value did not reach considerable risk level and stayed in the acceptable risk zone. Standard deviation was found as 9.39×10^{-6}. The frequency histogram and descriptive statistics are presented in the Figure 5.10.



Statistic	Forecast values
Trials	10.000
Base Case	3,15E-06
Mean	1,01E-05
Median	7,30E-06
Mode	---
Standard Deviat	9,39E-06
Variance	8,82E-11
Skewness	1,71
Kurtosis	6,96
Coeff. of Variati	0,9280
Minimum	5,22E-08
Maximum	8,39E-05
Mean Std. Error	9,39E-08

5,22E-08 Certainty: 99,99 % 8,39E-05

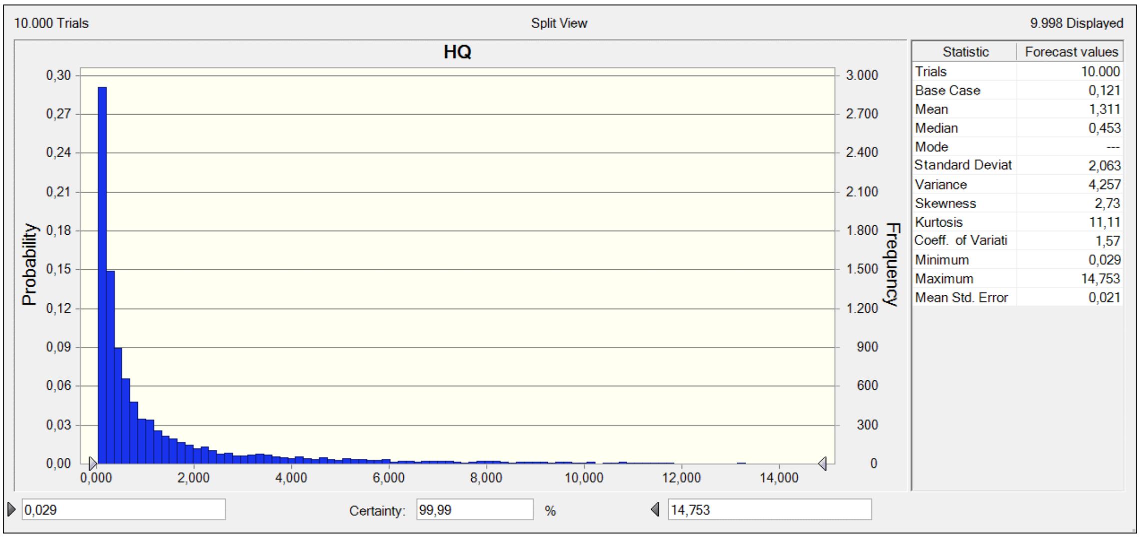
Figure 5.10. The frequency histogram and descriptive statistics of carcinogenic risk assessment of cauliflower

5.2.6. Corn

Bioconcentration factor data was fit a lognormal distribution. Location and standard deviation were 0 and 0.21138 respectively. Mean value was calculated as 0.04075. Minimum and maximum were 0.0004 and 0.23 respectively. Consumption rate data was fit a uniform distribution. Minimum and maximum consumption rate were 39.81 and 70.64 g/day respectively. Background arsenic concentration was entered as 25 µg/kg.

5.2.6.1. Non-carcinogenic Risk Assessment of Corn

The mean HQ was found as 1.311 while maximum and minimum were 0.029 and 14.753 respectively. Maximum HQ exceeded significant risk limit while mean HQ stayed in concern level. Skewness was found as 2.73 and signified that HQs closer to the mean are more likely to be encountered. The frequency histogram and descriptive statistics are presented in the Figure 5.11.



10.000 Trials | Split View | 9.998 Displayed

HQ

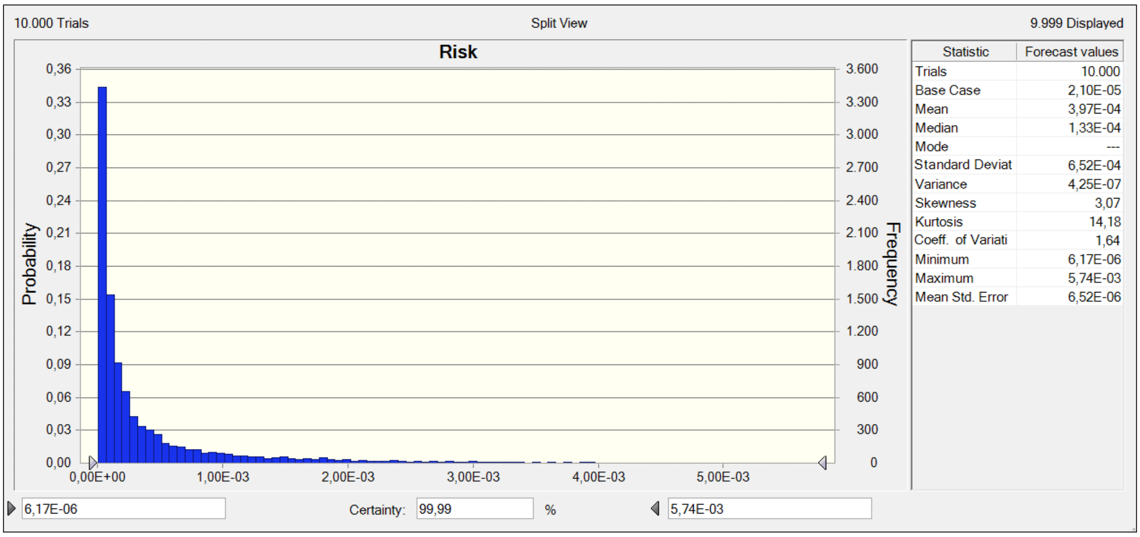
Statistic	Forecast values
Trials	10.000
Base Case	0,121
Mean	1,311
Median	0,453
Mode	---
Standard Deviat	2,063
Variance	4,257
Skewness	2,73
Kurtosis	11,11
Coeff. of Variati	1,57
Minimum	0,029
Maximum	14,753
Mean Std. Error	0,021

0,029 Certainty: 99,99 % 14,753

Figure 5.11. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of corn

5.2.6.2. Carcinogenic Risk Assessment of Corn

The mean risk value was found as 3.97×10^{-4} and reached significant risk level. Minimum and maximum risk values were found as 6.17×10^{-6} and 5.74×10^{-3} respectively. All of the risk values exceeded the acceptable risk limit. Skewness was found as 3.07. Thus, risk levels close to mean are more likely to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.12.



Statistic	Forecast values
Trials	10.000
Base Case	2,10E-05
Mean	3,97E-04
Median	1,33E-04
Mode	---
Standard Deviat	6,52E-04
Variance	4,25E-07
Skewness	3,07
Kurtosis	14,18
Coeff. of Variati	1,64
Minimum	6,17E-06
Maximum	5,74E-03
Mean Std. Error	6,52E-06

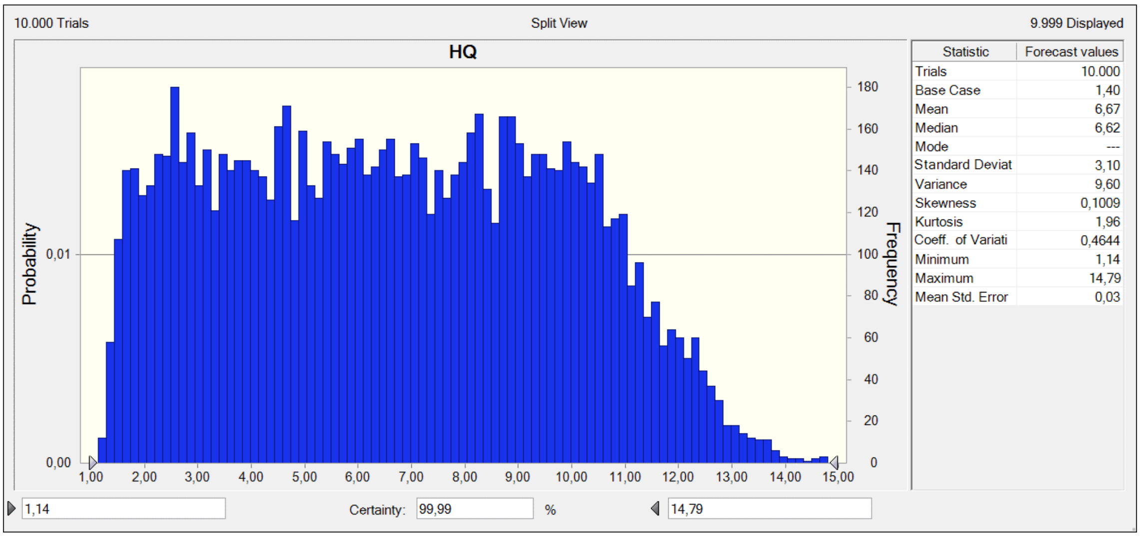
Figure 5.12. The frequency histogram and descriptive statistics of carcinogenic risk assessment of corn

5.2.7. Cucumber

Consumption rate data of the cucumber was fit a uniform distribution. Minimum and maximum values were 50.5 and 63.5 g/day respectively. Background arsenic concentration data was also fit a uniform distribution. Minimum value was entered as 3.4 µg/kg and maximum was 69.1 µg/kg. Bioconcentration factor was entered as a single value (0.34).

5.2.7.1. Non-carcinogenic Risk Assessment of the Cucumber

Minimum HQ value was found as 1.14 while maximum was found as 14.79. Mean HQ was found as 6.67. All of the HQ values exceeded the threshold limit. Skewness was found as 0.1009 which means values between 1.14 and 6.67 are more likely to occur. Standard deviation was found as 3.10. The frequency histogram and descriptive statistics are presented in Figure 5.13.



10.000 Trials | Split View | 9.999 Displayed

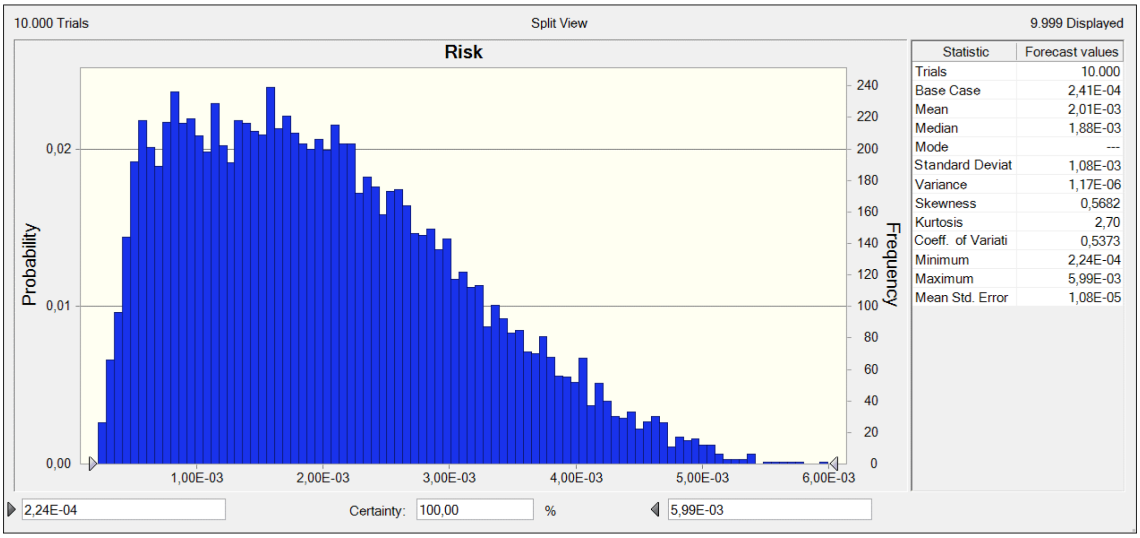
Statistic	Forecast values
Trials	10.000
Base Case	1,40
Mean	6,67
Median	6,62
Mode	---
Standard Deviat	3,10
Variance	9,60
Skewness	0,1009
Kurtosis	1,96
Coeff. of Variati	0,4644
Minimum	1,14
Maximum	14,79
Mean Std. Error	0,03

1,14 | Certainty: 99,99 % | 14,79

Figure 5.13. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the cucumber

5.2.7.1. Carcinogenic Risk Assessment of the Cucumber

Mean risk value was found as 2.01×10^{-3} and reached significant risk level. Minimum and maximum values were found as 2.24×10^{-4} and 5.99×10^{-3} respectively. All of the risk values exceeded the considerable risk limit. Skewness was found as 0.5682. Thus, risk levels close to mean are more likely to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.14.



10.000 Trials | Split View | 9.999 Displayed

Statistic	Forecast values
Trials	10.000
Base Case	2,41E-04
Mean	2,01E-03
Median	1,88E-03
Mode	---
Standard Deviat	1,08E-03
Variance	1,17E-06
Skewness	0,5682
Kurtosis	2,70
Coeff. of Variati	0,5373
Minimum	2,24E-04
Maximum	5,99E-03
Mean Std. Error	1,08E-05

2,24E-04 | Certainty: 100,00 % | 5,99E-03

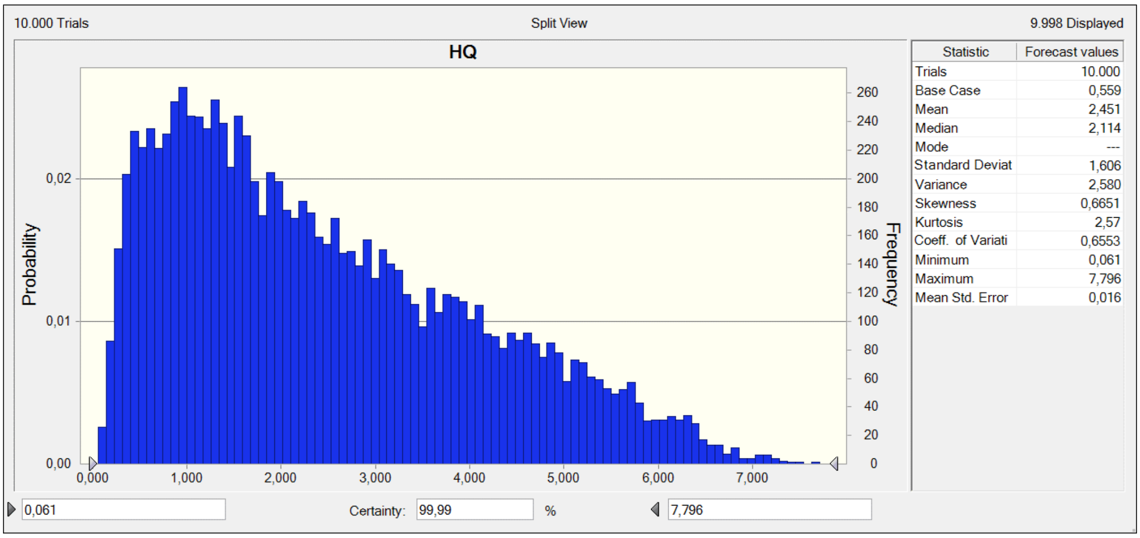
Figure 5.14. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the cucumber

5.2.8. Eggplant

Bioconcentration factor data was fit a uniform distribution and minimum and maximum values were 0.0010 and 0.19 respectively. Consumption rate data also fit a uniform distribution. Minimum value was 25.26 g/day while maximum was 33.66 g/day. Background arsenic concentration data was fit a uniform distribution. Minimum and maximum values were 80 and 410 µg/kg.

5.2.8.1. Non-carcinogenic Risk Assessment of Eggplant

Minimum hazard quotient value was 0.061 and stayed under the concern level. Mean and maximum HQ values were found as 2.451 and 7.796 respectively and exceeded significant risk level. Standard deviation was found as 1.606. The frequency histogram and descriptive statistics are presented in the Figure 5.15.



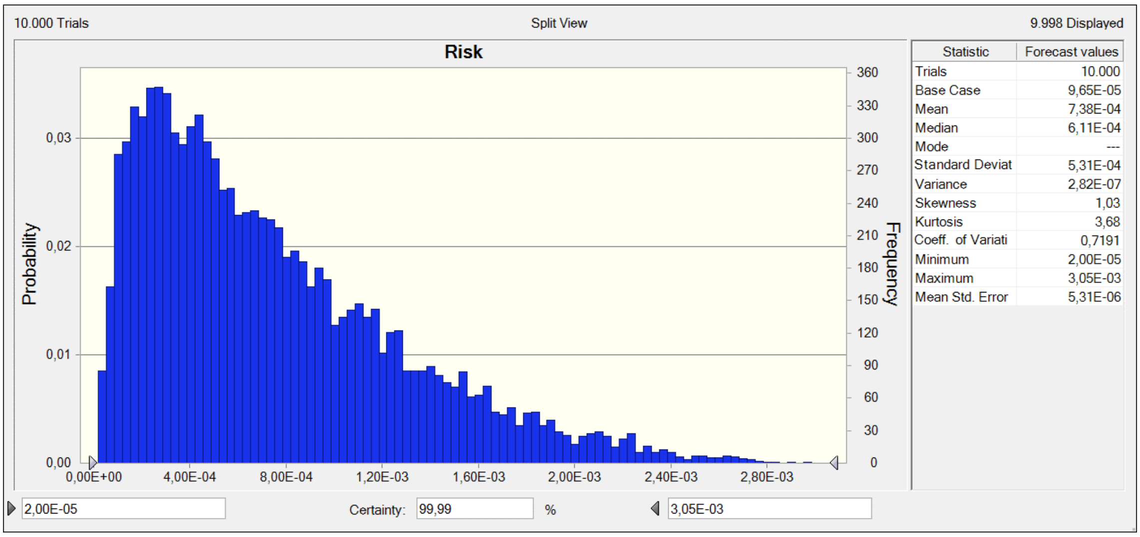
Statistic	Forecast values
Trials	10.000
Base Case	0,559
Mean	2,451
Median	2,114
Mode	---
Standard Deviat	1,606
Variance	2,580
Skewness	0,6651
Kurtosis	2,57
Coeff. of Variati	0,6553
Minimum	0,061
Maximum	7,796
Mean Std. Error	0,016

0,061 Certainty: 99,99 % 7,796

Figure 5.15. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of eggplant

5.2.8.1. Carcinogenic Risk Assessment of Eggplant

Minimum and maximum risk were found as 2.00×10^{-5} and 3.05×10^{-3} respectively. Mean risk was found as 7.38×10^{-4}. Skewness was found as 1.03. Hence, risk values between 2.00×10^{-5} and 7.38×10^{-4} are more possible. Howsoever, all of the risk values exceeded considerable risk level. Standard deviation was found as 5.31×10^{-4}. The frequency histogram and descriptive statistics are presented in the Figure 5.16.



Statistic	Forecast values
Trials	10.000
Base Case	9,65E-05
Mean	7,38E-04
Median	6,11E-04
Mode	---
Standard Deviat	5,31E-04
Variance	2,82E-07
Skewness	1,03
Kurtosis	3,68
Coeff. of Variati	0,7191
Minimum	2,00E-05
Maximum	3,05E-03
Mean Std. Error	5,31E-06

2,00E-05 Certainty: 99,99 % 3,05E-03

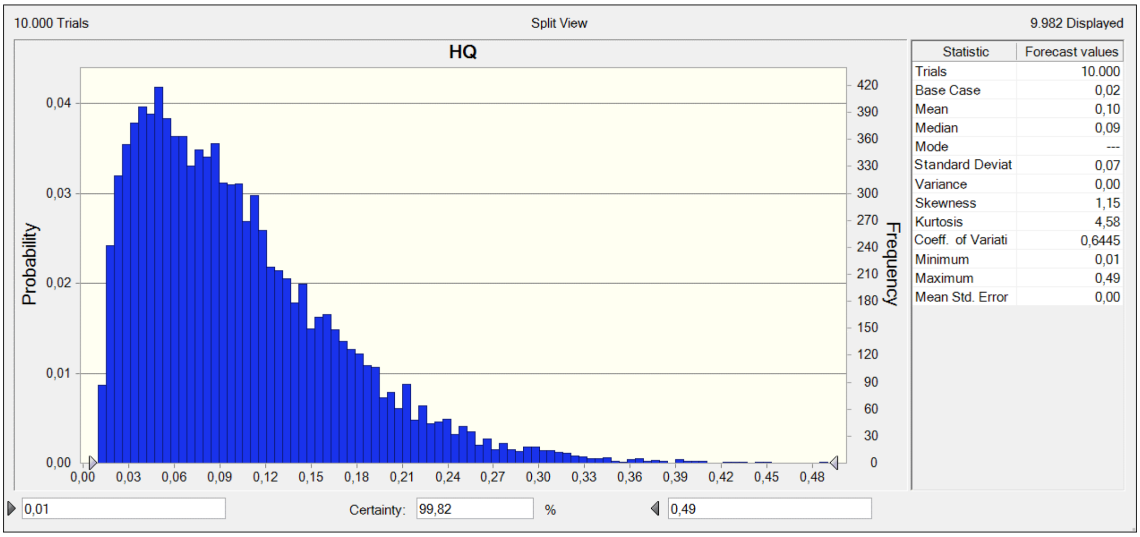
Figure 5.16. The frequency histogram and descriptive statistics of carcinogenic risk assessment of eggplant

5.2.9. Garlic

Bioconcentration factor was fit a uniform distribution. Minimum and maximum values were 0.02 and 0.05 respectively. Consumption rate data also was fit a uniform distribution and minimum value was 2.13 g/day while maximum was 2.85 g/day. Background arsenic concentration data was fit a uniform distribution which had values between a range of 8 to 20 µg/kg.

5.2.9.1. Non-carcinogenic Risk Assessment of Garlic

Minimum and maximum HQ values were found as 0.007 and 0.486 respectively. Mean HQ value calculated as 0.10. None of the HQ could not exceed the threshold limit. Standard deviation calculated as 0.065 and found close to zero. Skewness found as 1.15 and showed that HQ values lower than the mean are more possible to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.17.



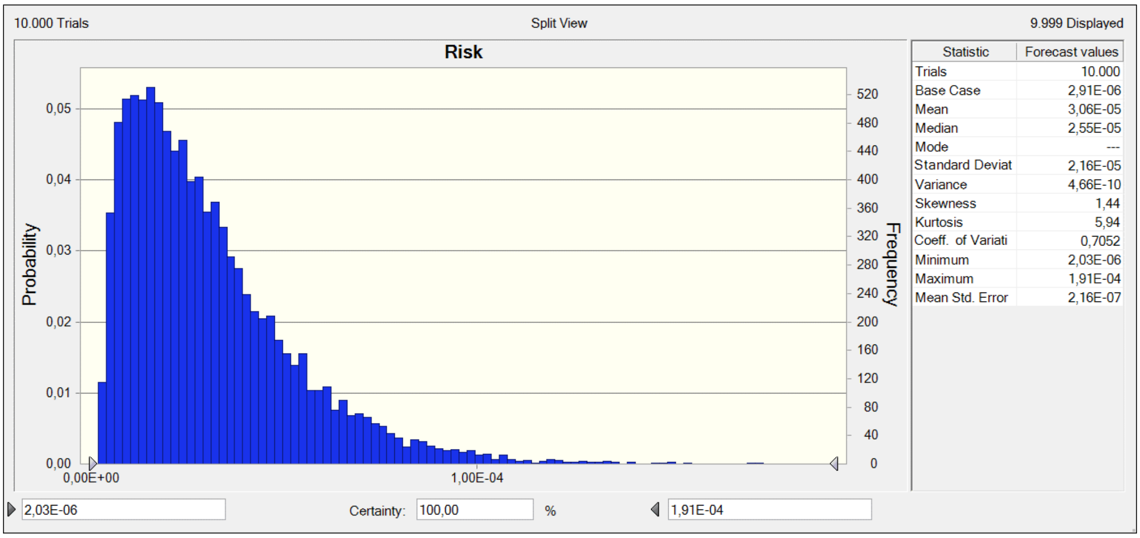
Statistic	Forecast values
Trials	10.000
Base Case	0,02
Mean	0,10
Median	0,09
Mode	---
Standard Deviat	0,07
Variance	0,00
Skewness	1,15
Kurtosis	4,58
Coeff. of Variati	0,6445
Minimum	0,01
Maximum	0,49
Mean Std. Error	0,00

0,01 Certainty: 99,82 % 0,49

Figure 5.17. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of garlic

5.2.9.1. Carcinogenic Risk Assessment of Garlic

Maximum risk value were found as 1.91×10^{-4} while minimum was 2.03×10^{-6}. Mean risk calculated as 3.06×10^{-5}. All of the risk values exceeded acceptable risk limit and maximum risk reached significant risk level. Skewness was found 1.44 and showed that values between 2.03×10^{-6} and 3.06×10^{-5} are more likely. Standard deviation was found as 2.16×10^{-5}. The frequency histogram and descriptive statistics are presented in the Figure 5.18.



Statistic	Forecast values
Trials	10.000
Base Case	2,91E-06
Mean	3,06E-05
Median	2,55E-05
Mode	---
Standard Deviat	2,16E-05
Variance	4,66E-10
Skewness	1,44
Kurtosis	5,94
Coeff. of Variati	0,7052
Minimum	2,03E-06
Maximum	1,91E-04
Mean Std. Error	2,16E-07

2,03E-06 Certainty: 100,00 % 1,91E-04

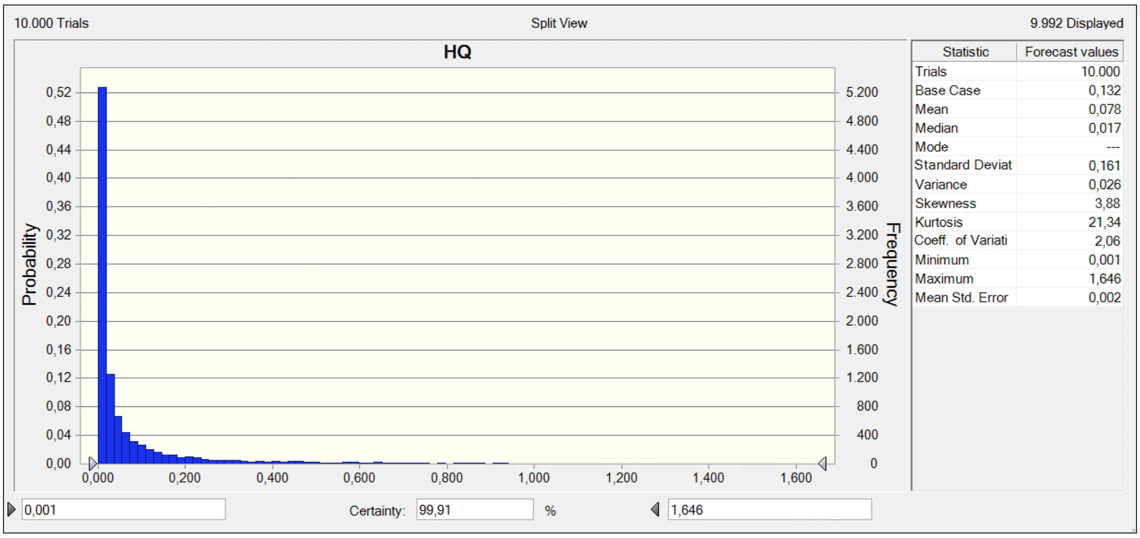
Figure 5.18. The frequency histogram and descriptive statistics of carcinogenic risk assessment of garlic

5.2.10. Lettuce

Bioconcentration factor was fit a lognormal distribution which had minimum and maximum values as 0.00022 and 0.11 respectively. Consumption rate was fit a uniform distribution. Minimum and maximum consumption rates were 11.62 g/day and 14.62 g/day. Background arsenic concentration data was fit a lognormal distribution which had mean value as 21.44 μg/kg. Maximum and minimum values were 102 μg/kg and 2 μg/kg respectively.

5.2.10.1. Non-carcinogenic Risk Assessment of Lettuce

Maximum HQ was found as 1.646 whilst minimum was 0.001. Mean HQ was estimated as 0.078. Standard deviation was calculated as 0.161. Maximum HQ value exceeded the threshold limit and reached concern level. However, skewness of the graph showed that HQ values lower than the mean HQ are more possible. The frequency histogram and descriptive statistics are presented in the Figure 5.19.



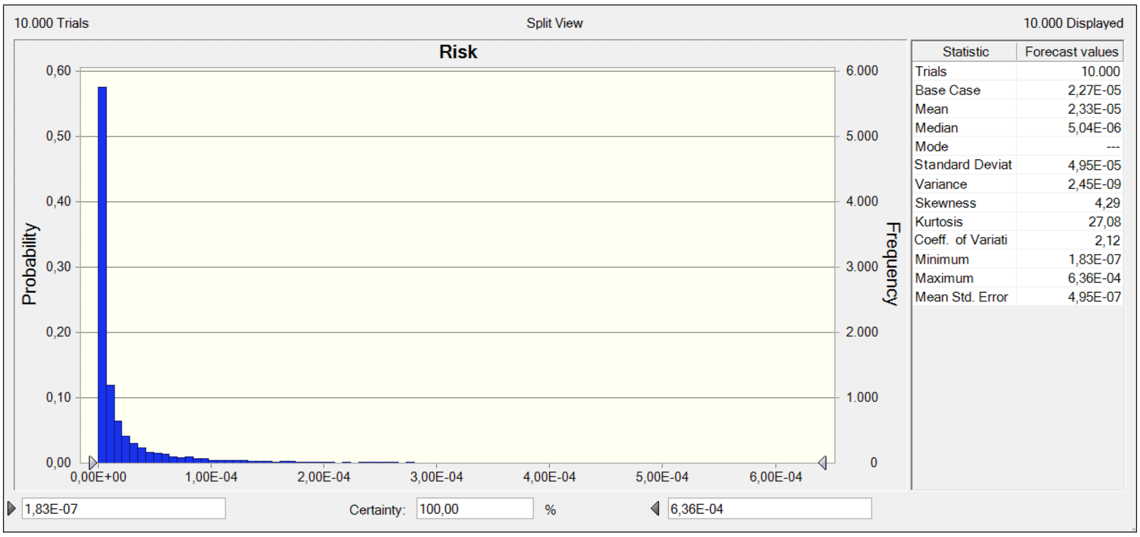
Statistic	Forecast values
Trials	10.000
Base Case	0,132
Mean	0,078
Median	0,017
Mode	---
Standard Deviat	0,161
Variance	0,026
Skewness	3,88
Kurtosis	21,34
Coeff. of Variati	2,06
Minimum	0,001
Maximum	1,646
Mean Std. Error	0,002

0,001 Certainty: 99,91 % 1,646

Figure 5.19. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the lettuce

5.2.10.2. Carcinogenic Risk Assessment of Lettuce

The mean risk value was found as 2.33×10^{-5} while minimum and maximum values were 1.83×10^{-7} and 6.36×10^{-4} respectively. Skewness was found as 4.29 and showed that risk values tend to be lower than the 2.33×10^{-5}. Standard deviation was 4.95×10^{-5}. The frequency histogram and descriptive statistics are presented in the Figure 5.20.



Statistic	Forecast values
Trials	10.000
Base Case	2,27E-05
Mean	2,33E-05
Median	5,04E-06
Mode	---
Standard Deviat	4,95E-05
Variance	2,45E-09
Skewness	4,29
Kurtosis	27,08
Coeff. of Variati	2,12
Minimum	1,83E-07
Maximum	6,36E-04
Mean Std. Error	4,95E-07

1,83E-07 Certainty: 100,00 % 6,36E-04

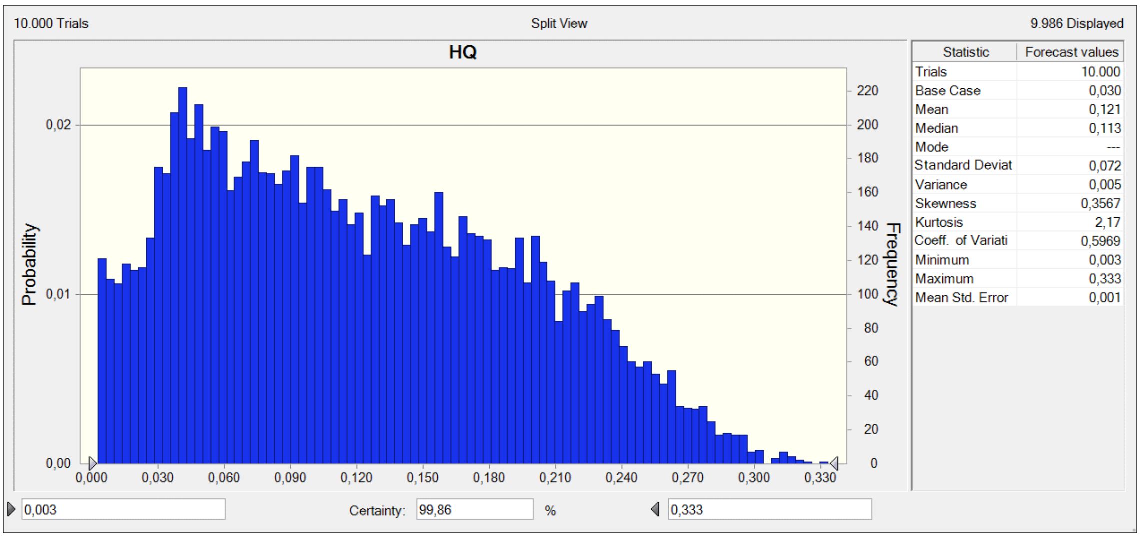
Figure 5.20. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the lettuce

5.2.11. Okra

Bioconcentration factor was fit a uniform distribution and its maximum and minimum values were 0.36 and 0.001 respectively. Consumption rate was fit a uniform distribution and its minimum and maximum values were 0.97 and 1.45 g/day. Background arsenic concentration was entered as 51 µg/kg.

5.2.11.1. Non-carcinogenic Risk Assessment of Okra

Minimum and maximum HQ values were found as 0.003 and 0.333 respectively. Mean HQ was calculated as 0.121. None of the values could not reached the significant risk level. Skewness was found as 0.3567. Standard deviation was found as 0.072. The frequency histogram and descriptive statistics are presented in the Figure 5.21.



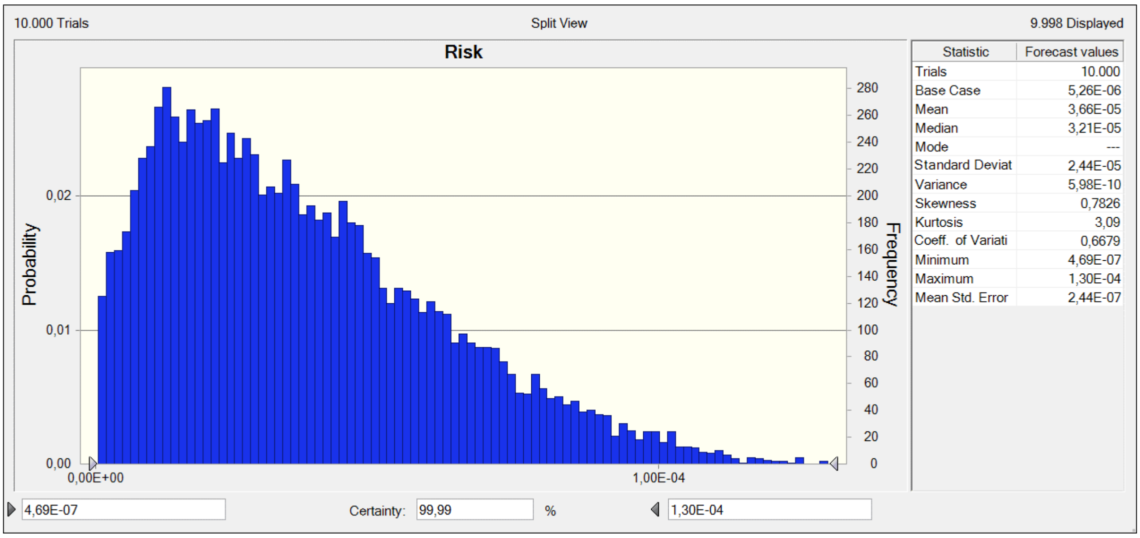
Statistic	Forecast values
Trials	10.000
Base Case	0,030
Mean	0,121
Median	0,113
Mode	---
Standard Deviat	0,072
Variance	0,005
Skewness	0,3567
Kurtosis	2,17
Coeff. of Variati	0,5969
Minimum	0,003
Maximum	0,333
Mean Std. Error	0,001

0,003 Certainty: 99,86 % 0,333

Figure 5.21. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the okra

5.2.11.2. Carcinogenic Risk Assessment of Okra

Maximum and minimum risk values were found as 1.30×10^{-4} and 4.69×10^{-7} respectively. Mean risk was 3.66×10^{-5} and exceeded the acceptable risk limit and reached considerable risk level. Maximum risk reached the significant risk level. However, skewness showed that risk values close to the mean risk are more likely to occur. The frequency histogram and descriptive statistics are presented in the Figure 5.22.



Statistic	Forecast values
Trials	10.000
Base Case	5,26E-06
Mean	3,66E-05
Median	3,21E-05
Mode	---
Standard Deviat	2,44E-05
Variance	5,98E-10
Skewness	0,7826
Kurtosis	3,09
Coeff. of Variati	0,6679
Minimum	4,69E-07
Maximum	1,30E-04
Mean Std. Error	2,44E-07

4,69E-07 Certainty: 99,99 % 1,30E-04

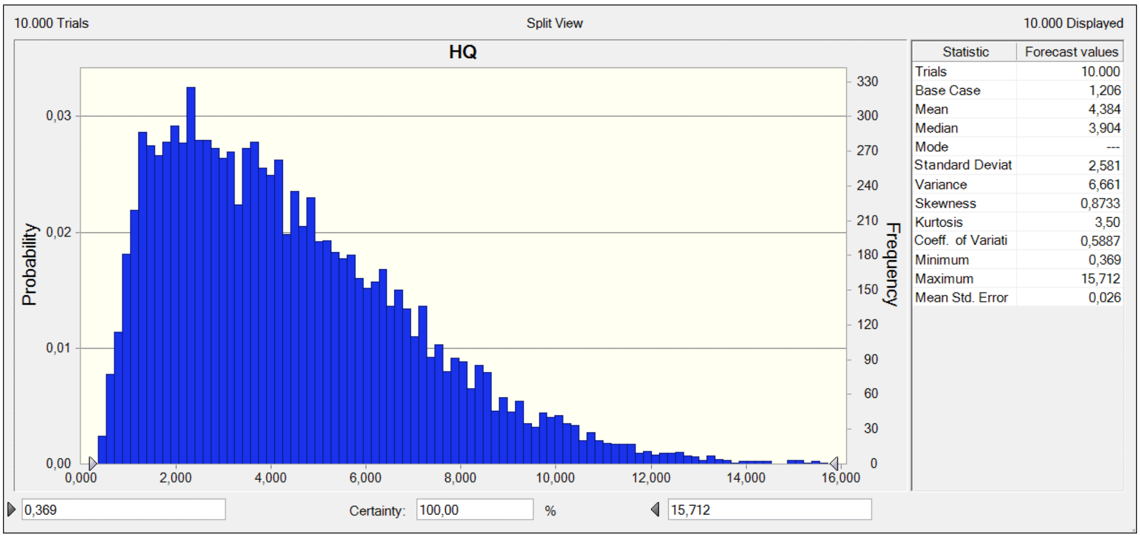
Figure 5.22. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the okra

5.2.12. Onion

Bioconcentration factor data was fit a uniform distribution and its values ranged between 0.048 and 0.07. Consumption rate was fit a uniform distribution and values ranged between 52.4 and 75.3 g/day. Background arsenic concentration was fit a pareto distribution. Its location was 2.17 and shape was 0.471. Minimum background arsenic concentration was 2.50 while maximum was 440 µg/kg.

5.2.12.1. Non-carcinogenic Risk Assessment of Onion

Minimum and maximum HQ values were calculated as 0.369 and 15.712 respectively. Mean HQ was 4.384 and reached the significant non-carcinogenic risk level. Skewness showed that data were almost equally scattered on the graph. Thus, higher HQ values are possible as much as lower HQ values. Standard deviation was found as 2.581. The frequency histogram and descriptive statistics are presented in the Figure 5.23.



Statistic	Forecast values
Trials	10.000
Base Case	1,206
Mean	4,384
Median	3,904
Mode	---
Standard Deviat	2,581
Variance	6,661
Skewness	0,8733
Kurtosis	3,50
Coeff. of Variati	0,5887
Minimum	0,369
Maximum	15,712
Mean Std. Error	0,026

0,369

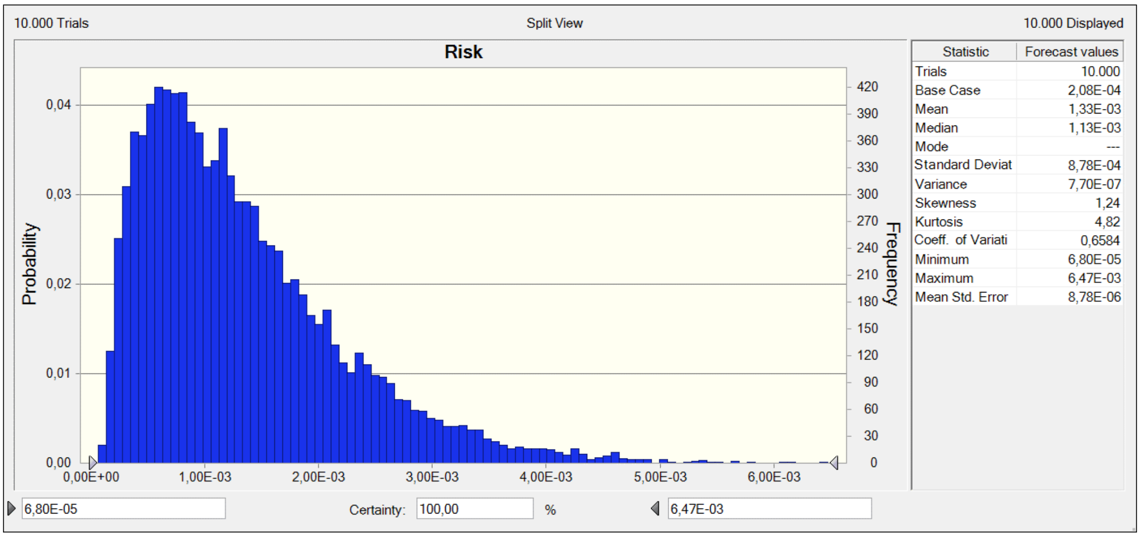
Certainty: 100,00 %

15,712

Figure 5.23. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the onion

5.2.12.2. Carcinogenic Risk Assessment of Onion

The minimum risk value was calculated as 6.80×10^{-5} and reached considerable risk level. Maximum risk value was found as 6.47×10^{-3} and exceeded the significant risk limit. Mean risk was calculated as 1.33×10^{-3} and reached significant risk level. Skewness found as 1.24 and showed that values between minimum risk and mean risk are more possible. Howsoever, all of the risk values signified important risk. Standard deviation was calculated as 8.78×10^{-4}. The frequency histogram and descriptive statistics are presented in the Figure 5.24.



Statistic	Forecast values
Trials	10.000
Base Case	2,08E-04
Mean	1,33E-03
Median	1,13E-03
Mode	---
Standard Deviat	8,78E-04
Variance	7,70E-07
Skewness	1,24
Kurtosis	4,82
Coeff. of Variati	0,6584
Minimum	6,80E-05
Maximum	6,47E-03
Mean Std. Error	8,78E-06

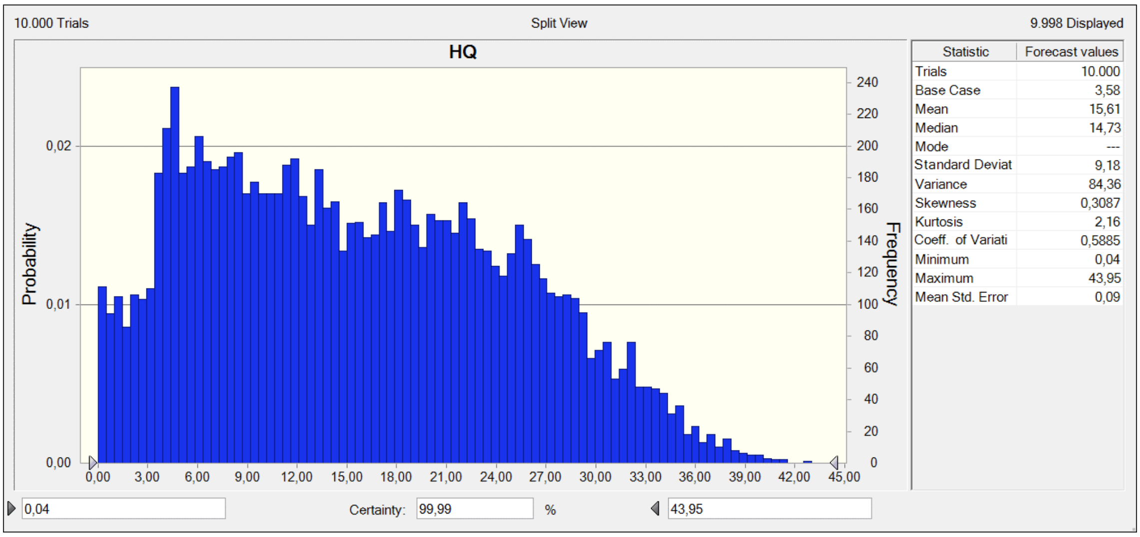
Figure 5.24. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the onion

5.2.13. Potato

Bioconcentration factor data was fit a uniform distribution and ranged between 0.00011 and 0.46. Consumption rate was fit a uniform distribution and had values between 122.01 and 185.40 g/day. Background arsenic concentration was fit a lognormal distribution. Minimum, mean and maximum values were 2, 11.86, and 460 µg/kg respectively. Location was 1.97 and standard deviation was 34.14.

5.2.13.1. Non-carcinogenic Risk Assessment of Potato

HQ values of potato were found between 0.04 and 43.95. Mean HQ value was 15.61 and reached an extreme value. Skewness was found as 0.3087 and HQ values between 0.04 and 15.61 are more likely. Howsoever, HQ values between minimum and maximum were still to high and represented significant risk. Standard deviation was found as 9.18 and showed wide range of HQs. The frequency histogram and descriptive statistics are presented in the Figure 5.25.



Statistic	Forecast values
Trials	10.000
Base Case	3,58
Mean	15,61
Median	14,73
Mode	---
Standard Deviat	9,18
Variance	84,36
Skewness	0,3087
Kurtosis	2,16
Coeff. of Variati	0,5885
Minimum	0,04
Maximum	43,95
Mean Std. Error	0,09

0,04

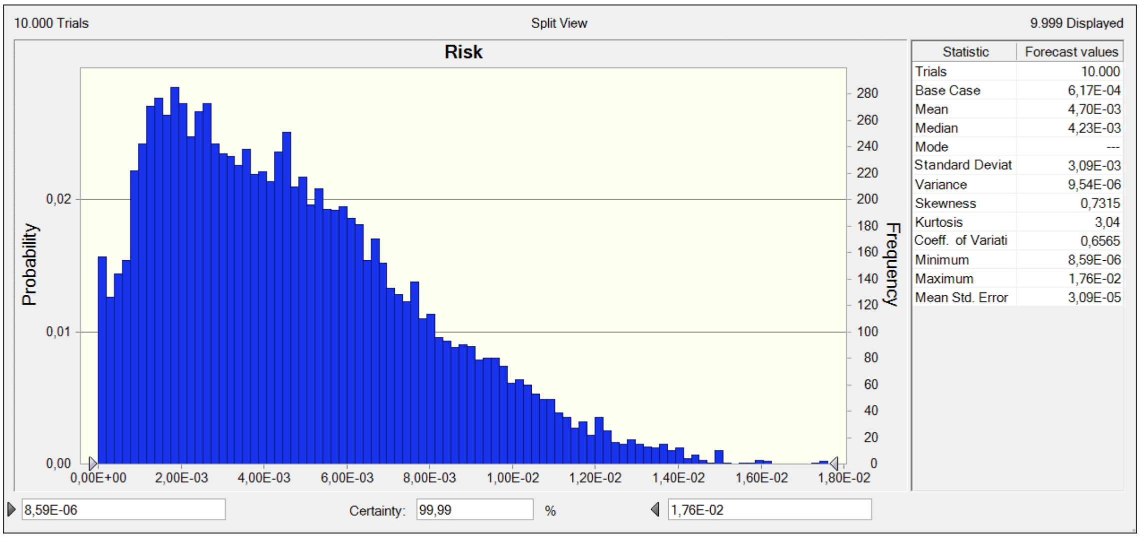
Certainty: 99,99 %

43,95

Figure 5.25. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the potato

5.2.13.2. Carcinogenic Risk Assessment of Potato

Minimum and maximum risk were found as 8.59×10^{-6} and 1.76×10^{-2} respectively. Mean risk was calculated 4.70×10^{-3} and exceeded significant risk limit. Skewness was found as 0.7315 and showed that data mostly scattered on the left side of the graph. Standard deviation was found as 3.09×10^{-3}. The frequency histogram and descriptive statistics are presented in the Figure 5.26.



Statistic	Forecast values
Trials	10.000
Base Case	6,17E-04
Mean	4,70E-03
Median	4,23E-03
Mode	---
Standard Deviat	3,09E-03
Variance	9,54E-06
Skewness	0,7315
Kurtosis	3,04
Coeff. of Variati	0,6565
Minimum	8,59E-06
Maximum	1,76E-02
Mean Std. Error	3,09E-05

8,59E-06

Certainty: 99,99 %

1,76E-02

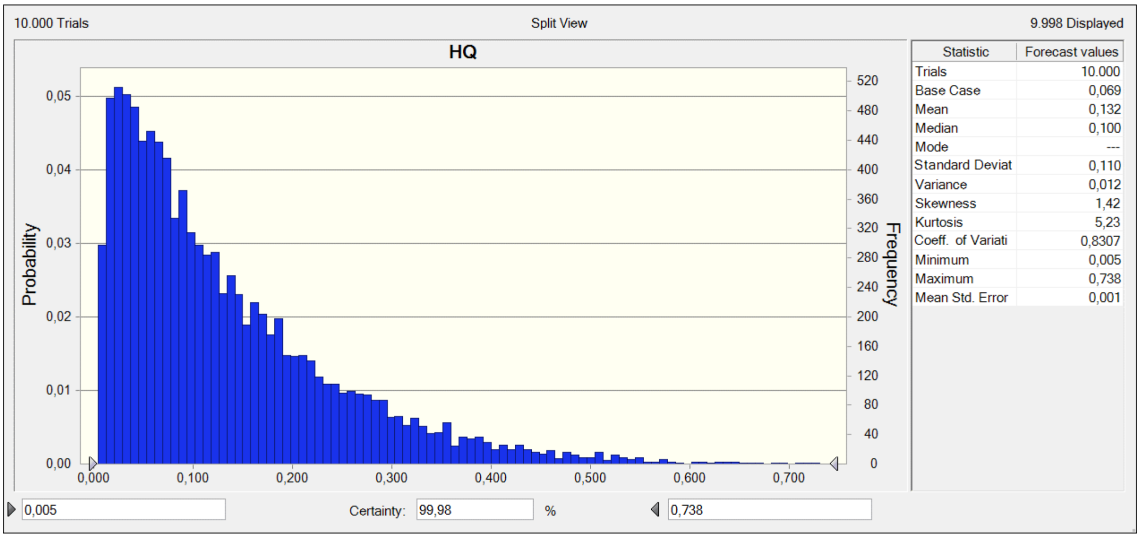
Figure 5.26. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the potato

5.2.14. Radish

Bioconcentration factor was fit a uniform distribution which had minimum and maximum values as 0.00063 and 0.05 respectively. Consumption rate was fit a uniform distribution and had values between a range of 5.07 and 6.17 g/day. Background arsenic concentrations were defined as uniform distribution. Minimum arsenic concentration was 45.7 µg/kg while maximum was 53.4 µg/kg.

5.2.14.1. Non-carcinogenic Risk Assessment of Radish

Minimum and maximum HQ values were found as 0.005 and 0.738 respectively. Mean HQ was calculated as 0.132 and could not reach concern level. Skewness was found as 1.42. Thus, HQ values between minimum and mean are more possible. Standard deviation was found as 0.110. The frequency histogram and descriptive statistics are presented in the Figure 5.27.



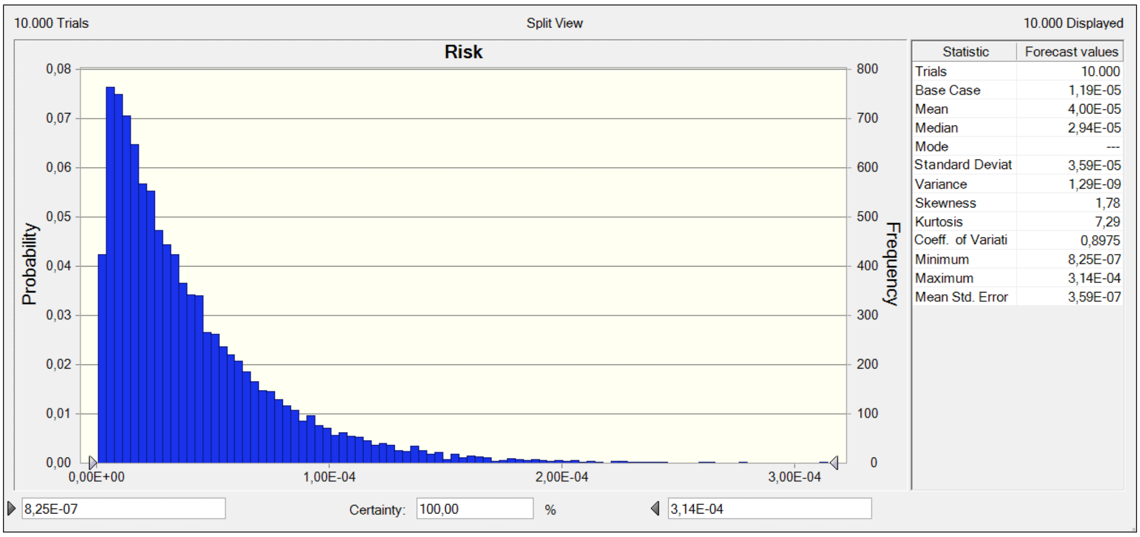
Statistic	Forecast values
Trials	10.000
Base Case	0,069
Mean	0,132
Median	0,100
Mode	---
Standard Deviat	0,110
Variance	0,012
Skewness	1,42
Kurtosis	5,23
Coeff. of Variati	0,8307
Minimum	0,005
Maximum	0,738
Mean Std. Error	0,001

0,005 Certainty: 99,98 % 0,738

Figure 5.27. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the radish

5.2.14.2. Carcinogenic Risk Assessment of Radish

Minimum risk value was found as 8.25×10^{-7} while maximum was 3.14×10^{-4}. Mean risk was 4.00×10^{-5}. All predicted risk values exceeded the acceptable risk limit. Standard deviation was calculated as 3.59×10^{-5}. Skewness was found as 1.78 and showed that data mostly concentrated on the left side of the graph. The frequency histogram and descriptive statistics are presented in the Figure 5.28.



10.000 Trials

10.000 Displayed

Statistic	Forecast values
Trials	10.000
Base Case	1,19E-05
Mean	4,00E-05
Median	2,94E-05
Mode	---
Standard Deviat	3,59E-05
Variance	1,29E-09
Skewness	1,78
Kurtosis	7,29
Coeff. of Variati	0,8975
Minimum	8,25E-07
Maximum	3,14E-04
Mean Std. Error	3,59E-07

8,25E-07

Certainty: 100,00 %

3,14E-04

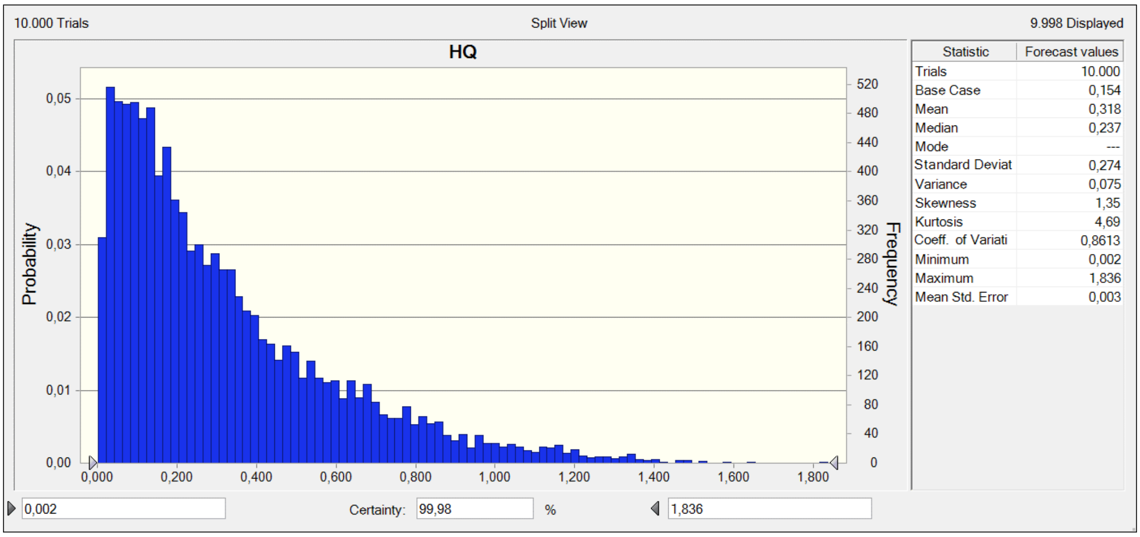
Figure 5.28. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the radish

5.2.15. Spinach

Bioconcentration factor data of spinach defined as uniform distribution which had minimum and maximum values as 0.00009 and 0.077 respectively. Consumption rate data was fit a uniform distribution. Minimum and maximum consumption rate values were 6.27 and 7.9 g/day. Background arsenic concentration was defined as uniform distribution. Minimum value was 3.5 µg/kg while maximum was 85 µg/kg.

5.2.15.1. Non-carcinogenic Risk Assessment of Spinach

Minimum and maximum HQ values of spinach were found as 0.002 and 1.836 respectively. Mean HQ value was calculated as 0.318. Skewness was found as 1.35 and showed that data mostly scattered on the left side of the graph. Howsoever, all HQ values stayed under the signifcant risk limit even though maximum HQ reached concern level. Standard deviation was 0.274. The frequency histogram and descriptive statistics are presented in the Figure 5.29.



10.000 Trials Split View 9.998 Displayed

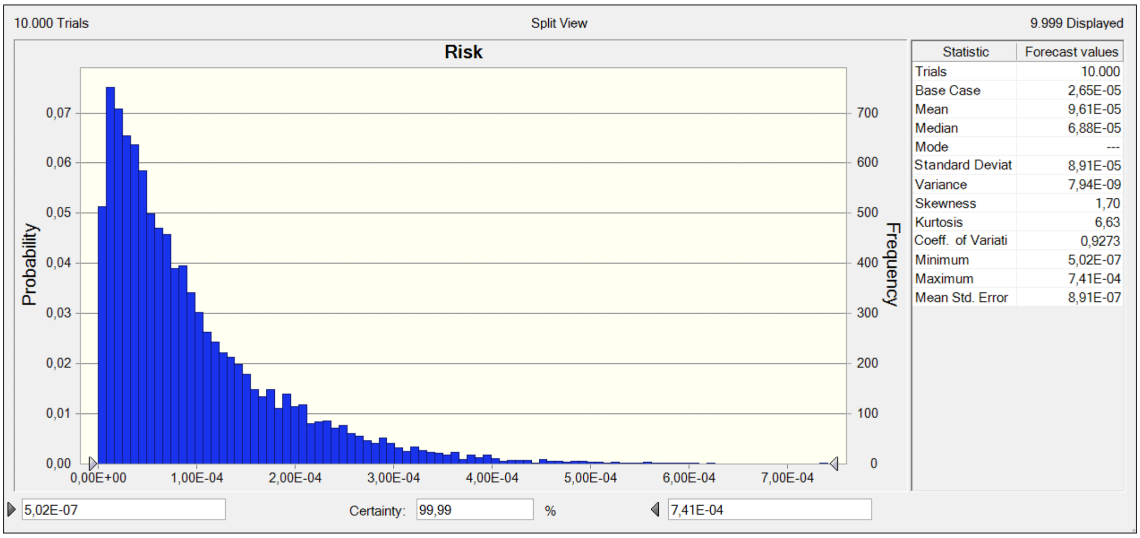
Statistic	Forecast values
Trials	10.000
Base Case	0,154
Mean	0,318
Median	0,237
Mode	---
Standard Deviat	0,274
Variance	0,075
Skewness	1,35
Kurtosis	4,69
Coeff. of Variati	0,8613
Minimum	0,002
Maximum	1,836
Mean Std. Error	0,003

0,002 Certainty: 99,98 % 1,836

Figure 5.29. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the spinach

5.2.15.2. Carcinogenic Risk Assessment of Spinach

Minimum and maximum risk values of spinach were found as 5.02×10^{-7} and 7.41×10^{-4}. Mean risk was 9.61×10^{-5}. Skewness was found as 1.70 and showed that values up to mean risk are more likely to occur. Maximum risk reached significant risk level while minimum stayed in the acceptable risk zone. Standard deviation was calculated as 8.91×10^{-5}. The frequency histogram and descriptive statistics are presented in the Figure 5.30.



10.000 Trials Split View 9.999 Displayed

Statistic	Forecast values
Trials	10.000
Base Case	2,65E-05
Mean	9,61E-05
Median	6,88E-05
Mode	---
Standard Deviat	8,91E-05
Variance	7,94E-09
Skewness	1,70
Kurtosis	6,63
Coeff. of Variati	0,9273
Minimum	5,02E-07
Maximum	7,41E-04
Mean Std. Error	8,91E-07

5,02E-07 Certainty: 99,99 % 7,41E-04

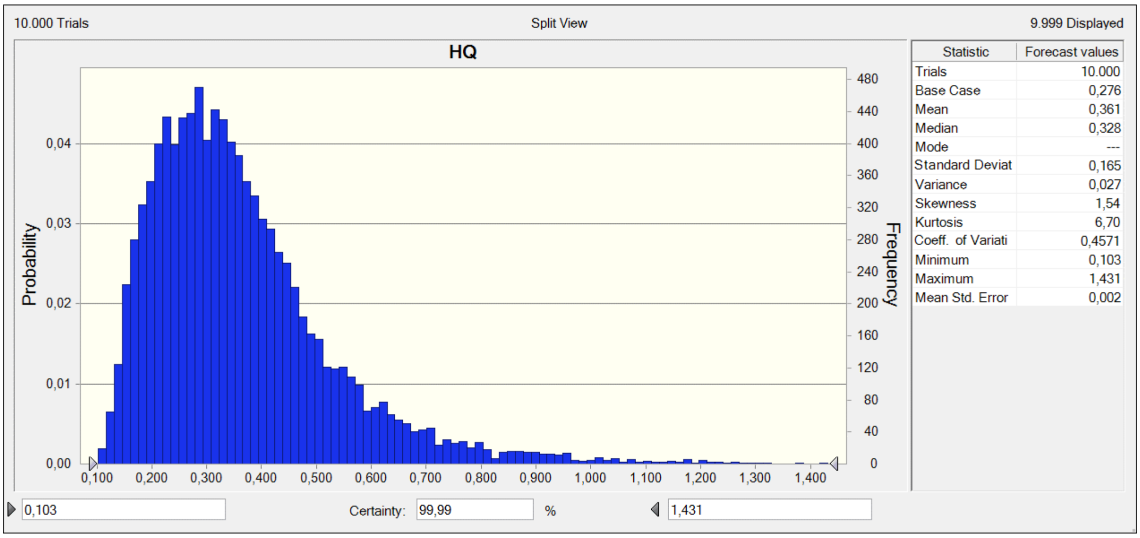
Figure 5.30. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the spinach

5.2.16. Sunflower

Consumption rate data was fit a uniform distribution minimum value was 38.44 while maximum was 112.33. Background arsenic concentration was entered as 69.1 µg/kg. Bioconcentration factor was entered as 0.003.

5.2.16.1. Non-carcinogenic Risk Assessment of Sunflower

Minimum and maximum HQ values of the sunflower were found as 0.103 and 1.431. Mean HQ was 0.361 and stayed under the concern limit even though the maximum HQ exceeded threshold limit and reached the concern level. Skewness was 1.54. Thus, data scattered on the left side of the graph. Standard deviation was 0.165. The frequency histogram and descriptive statistics are presented in the Figure 5.31.

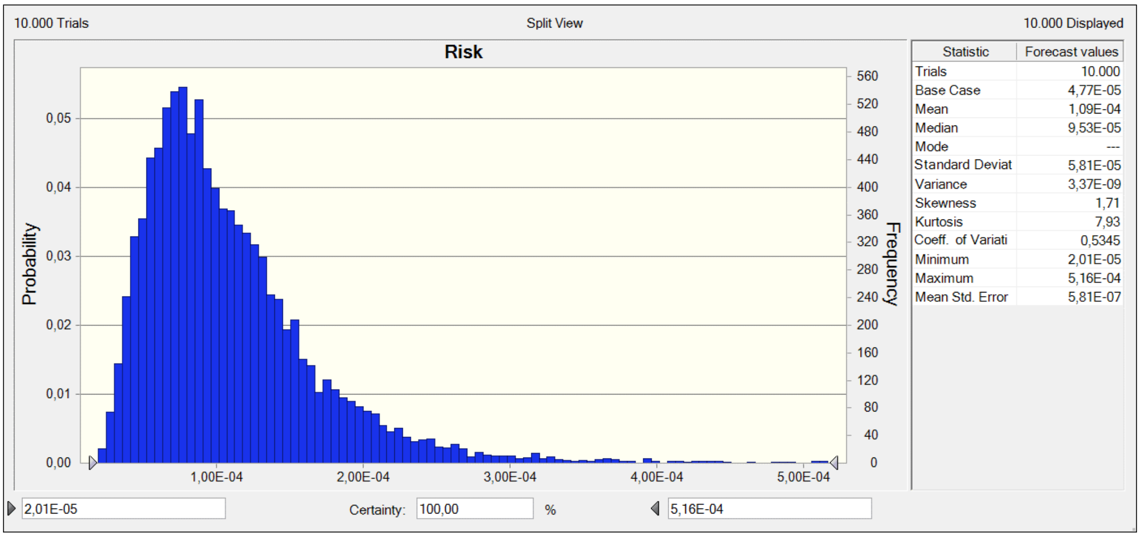


Statistic	Forecast values
Trials	10.000
Base Case	0,276
Mean	0,361
Median	0,328
Mode	---
Standard Deviat	0,165
Variance	0,027
Skewness	1,54
Kurtosis	6,70
Coeff. of Variati	0,4571
Minimum	0,103
Maximum	1,431
Mean Std. Error	0,002

Figure 5.31. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the sunflower

5.2.16.2. Carcinogenic Risk Assessment of Sunflower

Minimum and maximum risk values were found as 2.01×10^{-5} and 5.16×10^{-4} respectively. Mean risk was found as 1.09×10^{-4} and reached significant risk level. Skewness of the data was 1.71. Thus, values between 2.01×10^{-5} and 1.09×10^{-4} are more likely to be encountered. Standard deviation was calculated as 5.81×10^{-5}. The frequency histogram and descriptive statistics are presented in the Figure 5.32.



Statistic	Forecast values
Trials	10.000
Base Case	4,77E-05
Mean	1,09E-04
Median	9,53E-05
Mode	---
Standard Deviat	5,81E-05
Variance	3,37E-09
Skewness	1,71
Kurtosis	7,93
Coeff. of Variati	0,5345
Minimum	2,01E-05
Maximum	5,16E-04
Mean Std. Error	5,81E-07

2,01E-05 Certainty: 100,00 % 5,16E-04

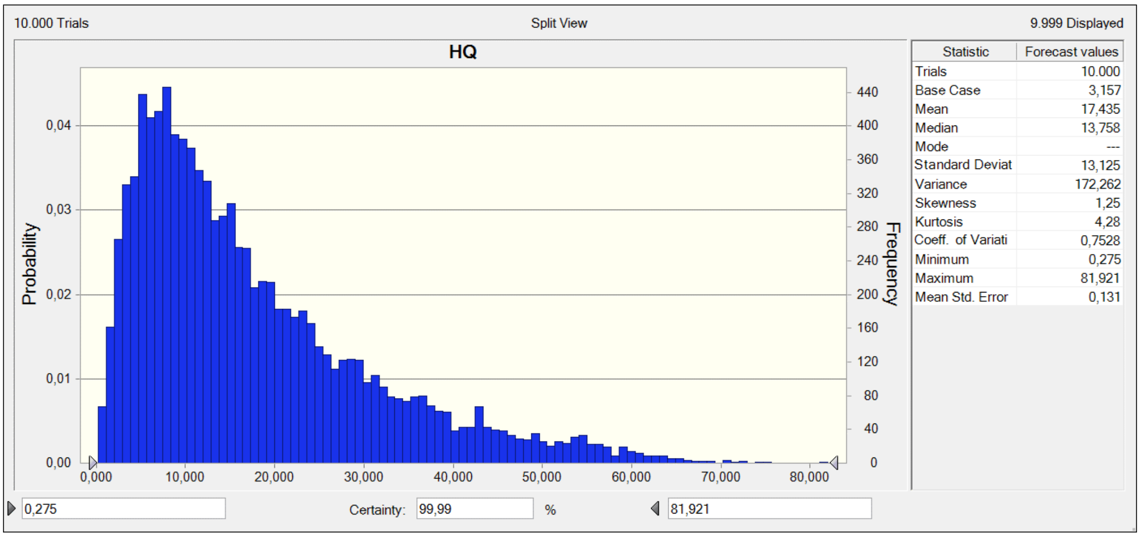
Figure 5.32. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the sunflower

5.2.17. Tomato

Bioconcentration factor data of the tomato was fit a uniform distribution which had a range between 0.001 and 0.1. Consumption rate data was fit a uniform distribution. Minimum consumption rate was 278.1 g/day while maximum consumption rate was 327.44 g/day. Background arsenic concentration was fit a uniform distribution. Minimum arsenic concentration was 0.46 µg/kg and maximum arsenic concentration was 520 µg/kg.

5.2.17.1. Non-carcinogenic Risk Assessment of Tomato

Minimum HQ of the tomato was found as 0.275 while maximum was 81.921. Mean HQ was found as 17.435 and reached significant risk level. Skewness was found as 1.25 and showed that values between minimum and mean are more possible. Standard deviation was 13.125. The frequency histogram and descriptive statistics are presented in the Figure 5.33.



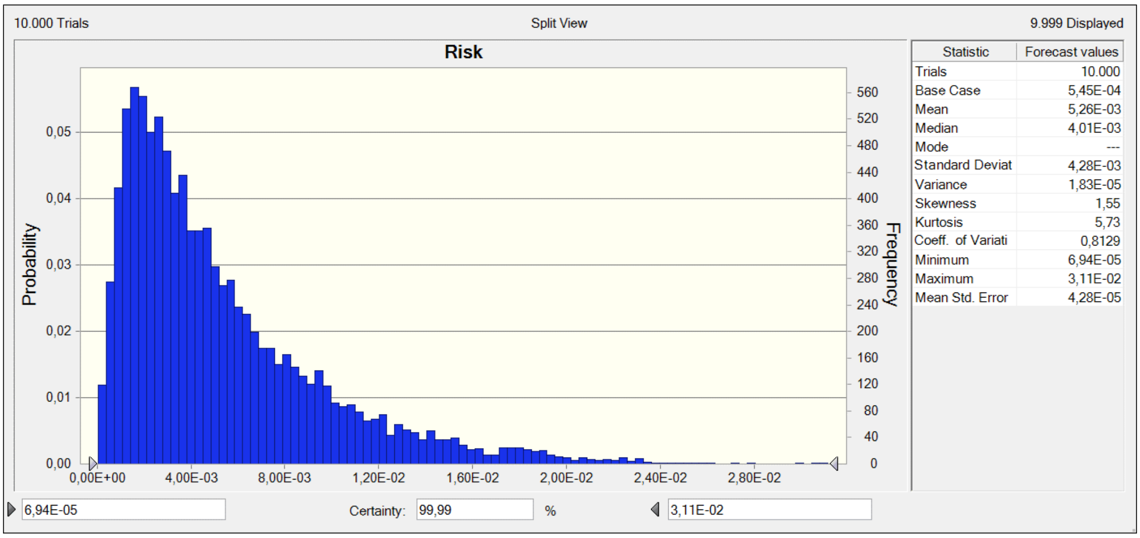
Statistic	Forecast values
Trials	10.000
Base Case	3,157
Mean	17,435
Median	13,758
Mode	---
Standard Deviat	13,125
Variance	172,262
Skewness	1,25
Kurtosis	4,28
Coeff. of Variati	0,7528
Minimum	0,275
Maximum	81,921
Mean Std. Error	0,131

0,275 Certainty: 99,99 % 81,921

Figure 5.33. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the tomato

5.2.17.2. Carcinogenic Risk Assessment of Tomato

Minimum risk was found as 6.94×10^{-5} while maximum was 3.11×10^{-2}. Mean risk was found as 5.26×10^{-3}. All risk values reached considerable risk level while maximum risk exceeded it and reached significant risk level. Standard deviation was calculated as 4.28×10^{-3}. Skewness was found as 1.55 and showed data mostly scattered on the left side of the graph. The frequency histogram and descriptive statistics are presented in the Figure 5.34.



Statistic	Forecast values
Trials	10.000
Base Case	5,45E-04
Mean	5,26E-03
Median	4,01E-03
Mode	---
Standard Deviat	4,28E-03
Variance	1,83E-05
Skewness	1,55
Kurtosis	5,73
Coeff. of Variati	0,8129
Minimum	6,94E-05
Maximum	3,11E-02
Mean Std. Error	4,28E-05

6,94E-05 Certainty: 99,99 % 3,11E-02

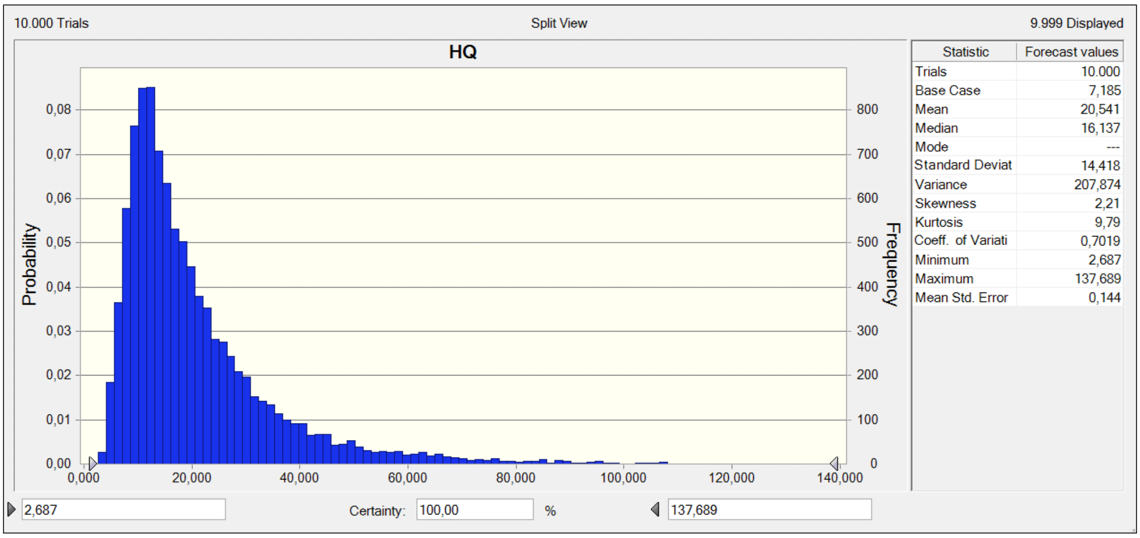
Figure 5.34. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the tomato

5.2.18. Wheat

Bioconcentration factor data of wheat was fit a maximum extreme distribution which has a range between 0.0067 to 0.088. Likeliest was 0.0192 and scale was 0.0125. Consumption rate was defined as uniform distribution and minimum and maximum values were 547.28 and 630.66 g/day. Background arsenic concentration was fit a uniform distribution and changed between 95 and 420 µg/kg.

5.2.18.1. Non-carcinogenic Risk Assessment of Wheat

Minimum and maximum HQ values were calculated as 2.687 and 137.689 respectively. Mean HQ value was found as 20.541. All HQ values exceeded the concern limit and reached significant risk level. Skewness was found as 2.21. Thus HQ values between 2.687 and 20.541 are more likely. Standard deviation was found as 14.418. The frequency histogram and descriptive statistics are presented in the Figure 5.35.

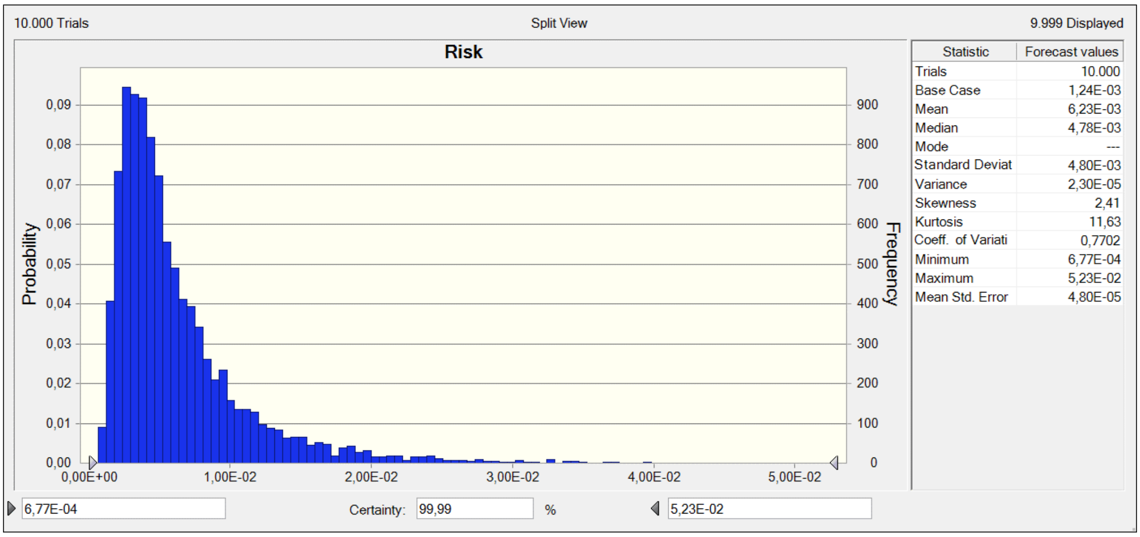


Statistic	Forecast values
Trials	10.000
Base Case	7,185
Mean	20,541
Median	16,137
Mode	---
Standard Deviat	14,418
Variance	207,874
Skewness	2,21
Kurtosis	9,79
Coeff. of Variati	0,7019
Minimum	2,687
Maximum	137,689
Mean Std. Error	0,144

Figure 5.35. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of wheat

5.2.18.2. Carcinogenic Risk Assessment of Wheat

Minimum and maximum risk values of wheat were found as 6.77×10^{-4} and 5.23×10^{-2} respectively. Mean risk was found as 6.32×10^{-3}. All risk values reached significant risk level. Skewness was found as 2.41. Thus, values between minimum and mean risk are more likely to be occured. Standard deviation was found as 4.80×10^{-3}. The frequency histogram and descriptive statistics are presented in the Figure 5.36.



Statistic	Forecast values
Trials	10.000
Base Case	1,24E-03
Mean	6,23E-03
Median	4,78E-03
Mode	---
Standard Deviat	4,80E-03
Variance	2,30E-05
Skewness	2,41
Kurtosis	11,63
Coeff. of Variati	0,7702
Minimum	6,77E-04
Maximum	5,23E-02
Mean Std. Error	4,80E-05

6,77E-04 Certainty: 99,99 % 5,23E-02

Figure 5.36. The frequency histogram and descriptive statistics of carcinogenic risk assessment of wheat

Percentile values of the non-carcinogenic risk assessment and carcinogenic risk assessment are given in Table 5.10 and Table 5.11 respectively. In the non-carcinogenic risk assessment, maximum HQ value was observed for wheat as 49.4 for the 95th percentile values. The 95th percentile values of potato, cucumber, onion, bean, tomato, eggplant, corn, and cabbage exceeded non-carcinogenic risk threshold. Among the all species, only tomato, wheat, potato, cucumber, and onion exceeded the threshold for the 5th percentile values.

In the carcinogenic risk assessment, wheat had the maximum risk level with 1.58×10^{-2} falling in the significant risk category for the 95th percentile risk values. Wheat was followed by tomato, potato, cucumber, onion, and eggplant respectively. Only lettuce, broccoli, and cauliflower had acceptable risk levels for the 5th percentile risk values.

Table 5.10. Percentile values of the non-carcinogenic risk for eighteen edible plant species

Percentiles	**Bean**	**Broccoli**	**Cabbage**	**Cauliflower**	**Carrot**	**Corn**	**Cucumber**	**Eggplant**	**Garlic**	**Lettuce**	**Okra**	**Onion**	**Potato**	**Radish**	**Spinach**	**Sunflower**	**Tomato**	**Wheat**
%0	0.15	0.00	0.02	0.00	0.00	0.03	1.14	0.06	0.01	0.00	0.00	0.37	0.04	0.00	0.00	0.10	0.27	2.69
%5	0.33	0.00	0.28	0.00	0.03	0.07	1.94	0.41	0.02	0.00	0.02	1.12	2.43	0.02	0.03	0.17	2.98	6.87
%10	0.42	0.00	0.50	0.00	0.04	0.09	2.47	0.60	0.03	0.00	0.03	1.45	4.11	0.02	0.05	0.19	4.36	8.24
%15	0.49	0.00	0.66	0.01	0.06	0.11	2.94	0.78	0.04	0.00	0.04	1.75	5.26	0.03	0.07	0.21	5.44	9.28
%20	0.56	0.00	0.80	0.01	0.07	0.13	3.49	0.96	0.04	0.01	0.05	2.05	6.48	0.04	0.09	0.23	6.54	10.24
%25	0.64	0.00	0.97	0.01	0.09	0.16	4.01	1.12	0.05	0.01	0.06	2.33	7.80	0.05	0.11	0.24	7.59	11.14
%30	0.70	0.00	1.13	0.01	0.10	0.20	4.55	1.30	0.06	0.01	0.07	2.63	9.08	0.06	0.13	0.26	8.61	11.97
%35	0.77	0.00	1.30	0.02	0.12	0.24	5.05	1.49	0.07	0.01	0.08	2.94	10.5	0.07	0.16	0.28	9.75	12.84
%40	0.84	0.00	1.48	0.02	0.14	0.30	5.59	1.67	0.07	0.01	0.09	3.25	11.8	0.08	0.18	0.29	11.0	13.8
%45	0.91	0.01	1.67	0.02	0.16	0.37	6.09	1.89	0.08	0.01	0.10	3.59	13.2	0.09	0.21	0.31	12.3	14.9
%50	0.98	0.01	1.87	0.03	0.18	0.45	6.62	2.11	0.09	0.02	0.11	3.90	14.7	0.10	0.24	0.33	13.8	16.1
%55	1.05	0.01	2.07	0.03	0.21	0.56	7.13	2.35	0.10	0.02	0.12	4.24	16.4	0.11	0.27	0.35	15.2	17.6
%60	1.12	0.01	2.29	0.03	0.24	0.70	7.69	2.61	0.10	0.03	0.14	4.63	18.0	0.13	0.31	0.37	17.0	19.0
%65	1.20	0.01	2.51	0.04	0.26	0.87	8.21	2.90	0.11	0.04	0.15	5.03	19.5	0.14	0.35	0.39	18.9	20.7
%70	1.28	0.01	2.74	0.04	0.30	1.11	8.73	3.20	0.12	0.05	0.16	5.48	21.1	0.16	0.39	0.41	21.3	22.7
%75	1.36	0.01	2.97	0.05	0.34	1.42	9.21	3.57	0.14	0.07	0.18	5.97	22.7	0.18	0.45	0.43	23.8	25.2
%80	1.45	0.01	3.21	0.06	0.39	1.88	9.73	3.93	0.15	0.09	0.19	6.52	24.5	0.21	0.52	0.46	27.1	28.1
%85	1.54	0.01	3.47	0.06	0.45	2.56	10.3	4.37	0.17	0.14	0.21	7.15	26.2	0.24	0.60	0.51	31.1	32.1
%90	1.64	0.01	3.75	0.08	0.55	3.76	10.8	4.87	0.19	0.21	0.22	7.99	28.4	0.29	0.71	0.57	36.4	38.1
%95	1.81	0.02	4.06	0.09	0.71	5.91	11.6	5.53	0.23	0.39	0.25	9.32	31.6	0.35	0.87	0.67	44.9	49.4
%100	2.40	0.05	5.48	0.21	1.99	14.8	14.8	7.80	0.49	1.65	0.33	15.7	44.0	0.74	1.84	1.43	81.9	137.7

Table 5.11. Percentile values of the carcinogenic risk for eighteen edible plant species

Percentiles	**Bean**	**Broccoli**	**Cabbage**	**Cauliflower**	**Carrot**	**Corn**	**Cucumber**	**Eggplant**	**Garlic**
%0	3.06×10^{-5}	1.91×10^{-7}	4.24×10^{-6}	5.22×10^{-8}	6.52×10^{-7}	6.17×10^{-6}	2.24×10^{-4}	2.00×10^{-5}	2.03×10^{-6}
%5	9.08×10^{-5}	5.22×10^{-7}	7.85×10^{-5}	6.83×10^{-7}	7.46×10^{-6}	1.87×10^{-5}	5.36×10^{-4}	1.16×10^{-4}	6.38×10^{-6}
%10	1.15×10^{-4}	6.74×10^{-7}	1.36×10^{-4}	1.33×10^{-6}	1.17×10^{-5}	2.47×10^{-5}	6.88×10^{-4}	1.70×10^{-4}	8.44×10^{-6}
%15	1.37×10^{-4}	7.97×10^{-7}	1.85×10^{-4}	1.92×10^{-6}	1.60×10^{-5}	3.08×10^{-5}	8.35×10^{-4}	2.22×10^{-4}	1.05×10^{-5}
%20	1.57×10^{-4}	9.16×10^{-7}	2.32×10^{-4}	2.60×10^{-6}	2.01×10^{-5}	3.87×10^{-5}	9.79×10^{-4}	2.70×10^{-4}	1.25×10^{-5}
%25	1.77×10^{-4}	1.04×10^{-6}	2.73×10^{-4}	3.28×10^{-6}	2.48×10^{-5}	4.71×10^{-5}	1.13×10^{-3}	3.19×10^{-4}	1.45×10^{-5}
%30	1.97×10^{-4}	1.17×10^{-6}	3.20×10^{-4}	3.98×10^{-6}	2.95×10^{-5}	5.79×10^{-5}	1.28×10^{-3}	3.73×10^{-4}	1.65×10^{-5}
%35	2.17×10^{-4}	1.30×10^{-6}	3.72×10^{-4}	4.74×10^{-6}	3.43×10^{-5}	7.18×10^{-5}	1.43×10^{-3}	4.27×10^{-4}	1.85×10^{-5}
%40	2.37×10^{-4}	1.44×10^{-6}	4.24×10^{-4}	5.52×10^{-6}	4.00×10^{-5}	8.87×10^{-5}	1.58×10^{-3}	4.81×10^{-4}	2.07×10^{-5}
%45	2.58×10^{-4}	1.58×10^{-6}	4.78×10^{-4}	6.39×10^{-6}	4.62×10^{-5}	1.10×10^{-4}	1.72×10^{-3}	5.44×10^{-4}	2.31×10^{-5}
%50	2.80×10^{-4}	1.74×10^{-6}	5.36×10^{-4}	7.30×10^{-6}	5.28×10^{-5}	1.33×10^{-4}	1.88×10^{-3}	6.11×10^{-4}	2.55×10^{-5}
%55	3.02×10^{-4}	1.91×10^{-6}	5.93×10^{-4}	8.30×10^{-6}	6.02×10^{-5}	1.64×10^{-4}	2.03×10^{-3}	6.83×10^{-4}	2.81×10^{-5}
%60	3.24×10^{-4}	2.08×10^{-6}	6.53×10^{-4}	9.44×10^{-6}	6.83×10^{-5}	2.04×10^{-4}	2.18×10^{-3}	7.58×10^{-4}	3.08×10^{-5}
%65	3.49×10^{-4}	2.29×10^{-6}	7.19×10^{-4}	1.08×10^{-5}	7.75×10^{-5}	2.53×10^{-4}	2.36×10^{-3}	8.38×10^{-4}	3.37×10^{-5}
%70	3.77×10^{-4}	2.53×10^{-6}	7.92×10^{-4}	1.23×10^{-5}	8.81×10^{-5}	3.27×10^{-4}	2.54×10^{-3}	9.35×10^{-4}	3.70×10^{-5}
%75	4.06×10^{-4}	2.82×10^{-6}	8.69×10^{-4}	1.41×10^{-5}	1.01×10^{-4}	4.22×10^{-4}	2.73×10^{-3}	1.04×10^{-3}	4.10×10^{-5}
%80	4.41×10^{-4}	3.19×10^{-6}	9.54×10^{-4}	1.63×10^{-5}	1.16×10^{-4}	5.57×10^{-4}	2.95×10^{-3}	1.16×10^{-3}	4.59×10^{-5}
%85	4.80×10^{-4}	3.62×10^{-6}	1.06×10^{-3}	1.93×10^{-5}	1.38×10^{-4}	7.73×10^{-4}	3.21×10^{-3}	1.31×10^{-3}	5.17×10^{-5}
%90	5.33×10^{-4}	4.30×10^{-6}	1.19×10^{-3}	2.29×10^{-5}	1.66×10^{-4}	1.12×10^{-3}	3.55×10^{-3}	1.51×10^{-3}	6.00×10^{-5}
%95	6.13×10^{-4}	5.55×10^{-6}	1.38×10^{-3}	2.95×10^{-5}	2.17×10^{-4}	1.78×10^{-3}	4.03×10^{-3}	1.80×10^{-3}	7.29×10^{-5}
%100	9.11×10^{-4}	2.27×10^{-5}	2.31×10^{-3}	8.39×10^{-5}	6.63×10^{-4}	5.74×10^{-3}	5.99×10^{-3}	3.05×10^{-3}	1.91×10^{-4}

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Table 5.11. (Cont.)

Percentiles	Lettuce	Okra	Onion	Potato	Radish	Spinach	Sunflower	Tomato	Wheat
%0	1.83×10^{-7}	4.69×10^{-7}	6.80×10^{-5}	8.59×10^{-6}	8.25×10^{-7}	5.02×10^{-7}	2.01×10^{-5}	6.94×10^{-5}	6.77×10^{-4}
%5	6.54×10^{-7}	5.22×10^{-6}	3.08×10^{-4}	6.83×10^{-4}	4.58×10^{-6}	8.48×10^{-6}	4.23×10^{-5}	8.41×10^{-4}	1.81×10^{-3}
%10	9.00×10^{-7}	8.76×10^{-6}	4.06×10^{-4}	1.13×10^{-3}	6.74×10^{-6}	1.39×10^{-5}	5.02×10^{-5}	1.21×10^{-3}	2.21×10^{-3}
%15	1.16×10^{-6}	1.16×10^{-5}	4.99×10^{-4}	1.49×10^{-3}	9.17×10^{-6}	1.95×10^{-5}	5.69×10^{-5}	1.53×10^{-3}	2.55×10^{-3}
%20	1.47×10^{-6}	1.42×10^{-5}	5.90×10^{-4}	1.85×10^{-3}	1.14×10^{-5}	2.53×10^{-5}	6.29×10^{-5}	1.82×10^{-3}	2.85×10^{-3}
%25	1.76×10^{-6}	1.71×10^{-5}	6.68×10^{-4}	2.20×10^{-3}	1.39×10^{-5}	3.14×10^{-5}	6.83×10^{-5}	2.14×10^{-3}	3.15×10^{-3}
%30	2.14×10^{-6}	1.98×10^{-5}	7.58×10^{-4}	2.57×10^{-3}	1.65×10^{-5}	3.75×10^{-5}	7.35×10^{-5}	2.48×10^{-3}	3.45×10^{-3}
%35	2.61×10^{-6}	2.26×10^{-5}	8.41×10^{-4}	2.96×10^{-3}	1.93×10^{-5}	4.47×10^{-5}	7.86×10^{-5}	2.80×10^{-3}	3.75×10^{-3}
%40	3.20×10^{-6}	2.57×10^{-5}	9.33×10^{-4}	3.36×10^{-3}	2.24×10^{-5}	5.16×10^{-5}	8.39×10^{-5}	3.17×10^{-3}	4.07×10^{-3}
%45	3.99×10^{-6}	2.87×10^{-5}	1.03×10^{-3}	3.80×10^{-3}	2.55×10^{-5}	6.01×10^{-5}	8.93×10^{-5}	3.58×10^{-3}	4.41×10^{-3}
%50	5.04×10^{-6}	3.21×10^{-5}	1.13×10^{-3}	4.23×10^{-3}	2.94×10^{-5}	6.88×10^{-5}	9.53×10^{-5}	4.01×10^{-3}	4.78×10^{-3}
%55	6.33×10^{-6}	3.54×10^{-5}	1.24×10^{-3}	4.63×10^{-3}	3.32×10^{-5}	7.81×10^{-5}	1.02×10^{-4}	4.48×10^{-3}	5.17×10^{-3}
%60	8.22×10^{-6}	3.92×10^{-5}	1.35×10^{-3}	5.10×10^{-3}	3.76×10^{-5}	8.87×10^{-5}	1.09×10^{-4}	4.99×10^{-3}	5.66×10^{-3}
%65	1.07×10^{-5}	4.31×10^{-5}	1.48×10^{-3}	5.57×10^{-3}	4.26×10^{-5}	1.01×10^{-4}	1.17×10^{-4}	5.60×10^{-3}	6.24×10^{-3}
%70	1.46×10^{-5}	4.69×10^{-5}	1.62×10^{-3}	6.09×10^{-3}	4.83×10^{-5}	1.15×10^{-4}	1.25×10^{-4}	6.29×10^{-3}	6.89×10^{-3}
%75	1.96×10^{-5}	5.17×10^{-5}	1.78×10^{-3}	6.64×10^{-3}	5.51×10^{-5}	1.33×10^{-4}	1.34×10^{-4}	7.13×10^{-3}	7.62×10^{-3}
%80	2.78×10^{-5}	5.73×10^{-5}	1.98×10^{-3}	7.29×10^{-3}	6.31×10^{-5}	1.54×10^{-4}	1.45×10^{-4}	8.17×10^{-3}	8.59×10^{-3}
%85	4.04×10^{-5}	6.37×10^{-5}	2.22×10^{-3}	8.10×10^{-3}	7.37×10^{-5}	1.82×10^{-4}	1.60×10^{-4}	9.42×10^{-3}	9.86×10^{-3}
%90	6.29×10^{-5}	7.16×10^{-5}	2.55×10^{-3}	9.15×10^{-3}	8.79×10^{-5}	2.19×10^{-4}	1.83×10^{-4}	1.11×10^{-2}	1.20×10^{-2}
%95	1.16×10^{-4}	8.39×10^{-5}	3.06×10^{-3}	1.05×10^{-2}	1.12×10^{-4}	2.77×10^{-4}	2.18×10^{-4}	1.42×10^{-2}	1.58×10^{-2}
%100	6.36×10^{-4}	1.30×10^{-4}	6.47×10^{-3}	1.76×10^{-2}	3.14×10^{-4}	7.41×10^{-4}	5.16×10^{-4}	3.11×10^{-2}	5.23×10^{-2}

5.3. Aggregate Risk for the Simav District

5.3.1. Deterministic Approach

Aggregate non-carcinogenic and carcinogenic risks were calculated to estimate the total arsenic exposure by consumption of all the studied foodstuff. Minimum aggregate non-carcinogenic risk was found for the lower-bound estimation of Scenario 3 as 9.74. Wheat was the plant variety that constitutes almost 63% of the aggregate exposure in the lower-bound estimate. Maximum aggregate non-carcinogenic risk was observed for the upper-bound estimate of Scenario 1 as 271. Wheat and tomato were the species that constitutes 60% of the aggregate non-carcinogenic risk. Aggregate non-carcinogenic risks are shown in Table 5.12.

Table 5.12. Aggregate non-carcinogenic risks calculated from deterministic approach

	Scenario 1			**Scenario 2**			**Scenario 3**		
	UB	**CT**	**LB**	**UB**	**CT**	**LB**	**UB**	**CT**	**LB**
Corn	11.5	0.66	0.04	5.77	0.35	0.04	1.21	0.11	0.04
Lettuce	1.59	0.04	0.00	0.80	0.02	0.00	0.16	0.01	0.00
Wheat	91.2	28.1	4.50	50.1	17.6	5.46	17.1	9.21	6.22
Radish	0.61	0.10	0.00	0.31	0.05	0.01	0.07	0.02	0.01
Potato	44.2	1.09	0.02	22.2	0.62	0.08	4.60	0.24	0.12
Spinach	0.75	0.05	0.00	0.38	0.03	0.01	0.09	0.01	0.01
Eggplant	8.46	0.18	0.04	4.41	0.22	0.13	1.17	0.25	0.21
Cauliflower	0.10	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.00
Cabbage	5.65	0.56	0.05	2.83	0.29	0.03	0.57	0.06	0.01
Tomato	70.5	4.80	1.02	36.0	3.05	1.09	8.48	1.64	1.14
Broccoli	0.02	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01
Okra	0.33	0.25	0.02	0.16	0.13	0.01	0.04	0.03	0.00
Carrot	1.97	1.08	0.06	1.00	0.55	0.04	0.22	0.13	0.01
Onion	16.2	8.16	3.43	8.22	4.18	1.80	1.87	1.00	0.50
Garlic	0.40	0.19	0.06	0.20	0.09	0.03	0.04	0.02	0.01
Cucumber	14.8	11.3	10.4	7.45	5.67	5.25	1.56	1.19	1.10
Sunflower seed	0.99	0.45	0.15	0.66	0.34	0.14	0.39	0.25	0.14
Bean	2.27	1.76	1.48	1.18	0.91	0.77	0.31	0.24	0.20
Aggregate HQ	271	58.7	21.3	142	34.1	14.9	37.9	14.4	9.74

Aggregate carcinogenic risks were ranged between 2.86×10^{-3} and 1.21×10^{-1}. Minimum aggregate carcinogenic risk was observed for the lower-bound estimate of Scenario 3 while maximum aggregate carcinogenic risk was observed for the upper-bound estimation of Scenario 1. Aggregate carcinogenic risks are listed in Table 5.13.

Table 5.13. Aggregate carcinogenic risks calculated from deterministic approach

	Scenario 1			Scenario 2			Scenario 3		
	UB	**CT**	**LB**	**UB**	**CT**	**LB**	**UB**	**CT**	**LB**
Corn	5.1×10^{-3}	2.5×10^{-4}	1.1×10^{-5}	2.6×10^{-3}	1.3×10^{-4}	1.1×10^{-5}	5.4×10^{-4}	4.2×10^{-5}	1.2×10^{-5}
Lettuce	7.1×10^{-4}	1.7×10^{-5}	1.3×10^{-6}	3.5×10^{-4}	9.4×10^{-6}	1.3×10^{-6}	7.3×10^{-5}	3.4×10^{-6}	1.2×10^{-6}
Wheat	4.1×10^{-2}	1.1×10^{-2}	1.3×10^{-3}	2.2×10^{-2}	6.7×10^{-3}	1.6×10^{-3}	7.6×10^{-3}	3.5×10^{-3}	1.8×10^{-3}
Radish	2.7×10^{-4}	3.8×10^{-5}	1.2×10^{-6}	1.4×10^{-4}	2.1×10^{-5}	1.8×10^{-6}	3.2×10^{-5}	6.9×10^{-6}	2.2×10^{-6}
Potato	2.0×10^{-2}	4.1×10^{-4}	6.9×10^{-6}	9.9×10^{-3}	2.3×10^{-4}	2.2×10^{-5}	2.0×10^{-3}	9.1×10^{-5}	3.5×10^{-5}
Spinach	3.3×10^{-4}	1.8×10^{-5}	1.1×10^{-6}	1.7×10^{-4}	1.1×10^{-5}	1.9×10^{-6}	3.9×10^{-5}	5.4×10^{-6}	2.5×10^{-6}
Eggplant	3.8×10^{-3}	6.8×10^{-5}	1.3×10^{-5}	2.0×10^{-3}	8.2×10^{-5}	4.0×10^{-5}	5.2×10^{-4}	9.4×10^{-5}	6.1×10^{-5}
Cauliflower	4.4×10^{-5}	1.4×10^{-6}	2.2×10^{-7}	2.2×10^{-5}	7.7×10^{-7}	1.7×10^{-7}	4.6×10^{-6}	2.8×10^{-7}	1.2×10^{-7}
Cabbage	2.5×10^{-3}	2.1×10^{-4}	1.5×10^{-5}	1.3×10^{-3}	1.1×10^{-4}	8.4×10^{-6}	2.6×10^{-4}	2.4×10^{-5}	3.3×10^{-6}
Tomato	3.1×10^{-2}	1.8×10^{-3}	3.0×10^{-4}	1.6×10^{-2}	1.2×10^{-3}	3.2×10^{-4}	3.8×10^{-3}	6.2×10^{-4}	3.4×10^{-4}
Broccoli	1.1×10^{-5}	6.2×10^{-6}	1.2×10^{-6}	7.4×10^{-6}	4.5×10^{-6}	1.6×10^{-6}	4.5×10^{-6}	3.1×10^{-6}	2.0×10^{-6}
Okra	1.4×10^{-4}	9.4×10^{-5}	7.3×10^{-6}	7.3×10^{-5}	4.7×10^{-5}	4.0×10^{-6}	1.6×10^{-5}	1.0×10^{-5}	1.3×10^{-6}
Carrot	8.8×10^{-4}	4.1×10^{-4}	1.8×10^{-5}	4.5×10^{-4}	2.1×10^{-4}	1.0×10^{-5}	9.9×10^{-5}	4.8×10^{-5}	4.1×10^{-6}
Onion	7.2×10^{-3}	3.1×10^{-3}	1.0×10^{-3}	3.7×10^{-3}	1.6×10^{-3}	5.3×10^{-4}	8.3×10^{-4}	3.8×10^{-4}	1.5×10^{-4}
Garlic	1.8×10^{-4}	7.0×10^{-5}	1.9×10^{-5}	8.9×10^{-5}	3.6×10^{-5}	9.4×10^{-6}	1.8×10^{-5}	7.5×10^{-6}	2.2×10^{-6}
Cucumber	6.6×10^{-3}	4.3×10^{-3}	3.1×10^{-3}	3.3×10^{-3}	2.1×10^{-3}	1.5×10^{-3}	6.9×10^{-4}	4.5×10^{-4}	3.2×10^{-4}
Sunflower	4.4×10^{-4}	1.7×10^{-4}	4.4×10^{-5}	2.9×10^{-4}	1.3×10^{-4}	4.2×10^{-5}	1.7×10^{-4}	9.6×10^{-5}	4.0×10^{-5}
Bean	1.0×10^{-3}	6.7×10^{-4}	4.3×10^{-4}	5.3×10^{-4}	3.5×10^{-4}	2.3×10^{-4}	1.4×10^{-4}	9.0×10^{-5}	6.0×10^{-5}
Aggregate Risk	1.2×10^{-1}	2.2×10^{-2}	6.3×10^{-3}	6.3×10^{-2}	1.3×10^{-2}	4.4×10^{-3}	1.7×10^{-2}	5.5×10^{-3}	2.9×10^{-3}

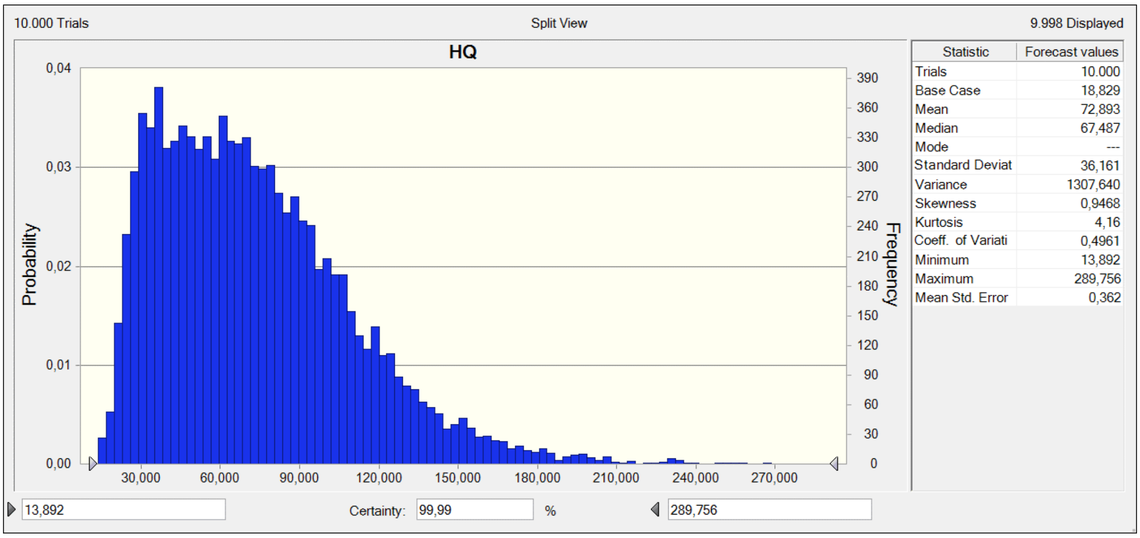
5.3.2. Probabilistic Approach

Monte Carlo simulation was run with three different sampling sizes, which were 10,000, 100,000, and 500,000. For n=10,000, aggregate non-carcinogenic risk varied between 13.9 and 290. The mean aggregate chronic-toxic risk was found as 72.9 and the median was found as 67.5. Standard deviation was found as 36.2. Figure 5.37 shows the aggregate chronic-toxic risk results for n=10,000. Aggregate carcinogenic risk ranged between 2.84×10^{-3} and 1.15×10^{-1}. The mean aggregate carcinogenic risk was found as 2.20×10^{-2} and indicated significant risk. Standard deviation was found as 1.25×10^{-2}. Figure 5.38 shows aggregate carcinogenic risk results for n=10,000.

For the simulation with a sample size of 100,000, aggregate non-carcinogenic risk ranged between 9.40 and 289. The mean estimated non-carcinogenic risk was 73. Standard deviation was found as 35.7. Aggregate carcinogenic risk varied between 1.86×10^{-3} and 1.19×10^{-1}. The mean carcinogenic risk was 2.21×10^{-2} and standard deviation was 1.23×10^{-2}. Figure 5.39 and Figure 5.40 show aggregate non-carcinogenic and aggregate carcinogenic risk assessments, respectively.

Aggregate non-carcinogenic risk assessment or a population of 500,000 varied between 9.4 and 307. The mean aggregate non-carcinogenic risk was found as 73 and standard deviation was 35.8. Figure 5.41 shows aggregate chronic-toxic risk results of the probabilistic approach for the population with 500,000 people. Aggregate carcinogenic risk assessment results ranged between 1.88×10^{-3} and 1.14×10^{-1}. The mean estimated risk was 2.21×10^{-2} and standard deviation was 1.24×10^{-2}. Figure 5.42 shows aggregate carcinogenic risk results of the probabilistic approach for the population with 500,000 people.

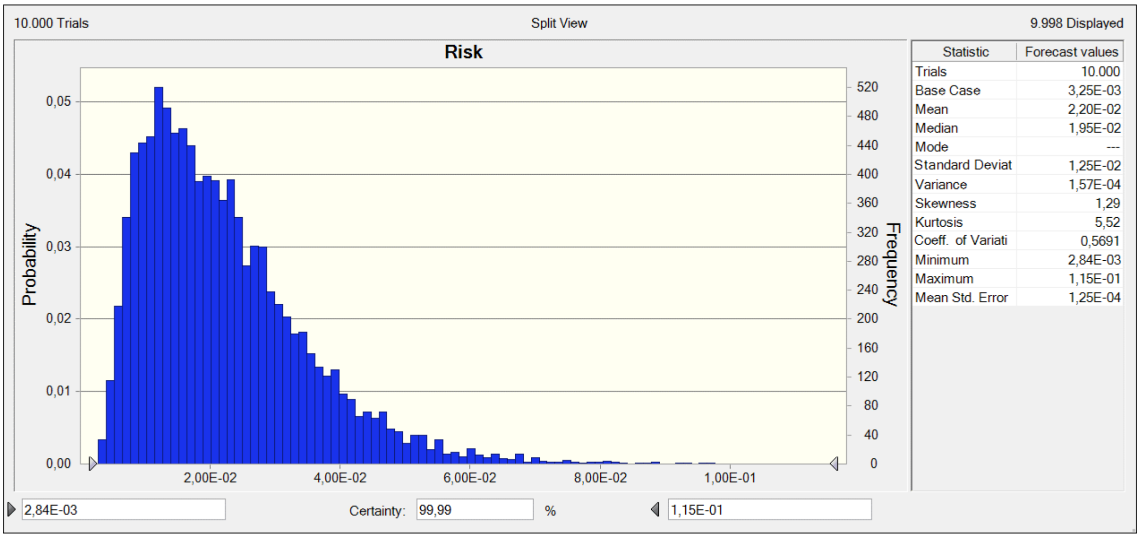
Results of the aggregate risk assessments with three different sampling sizes showed that the number of trials above 10,000 does not have an important effect on the estimated risks.



Statistic	Forecast values
Trials	10.000
Base Case	18,829
Mean	72,893
Median	67,487
Mode	---
Standard Deviat	36,161
Variance	1307,640
Skewness	0,9468
Kurtosis	4,16
Coeff. of Variati	0,4961
Minimum	13,892
Maximum	289,756
Mean Std. Error	0,362

13,892 Certainty: 99,99 % 289,756

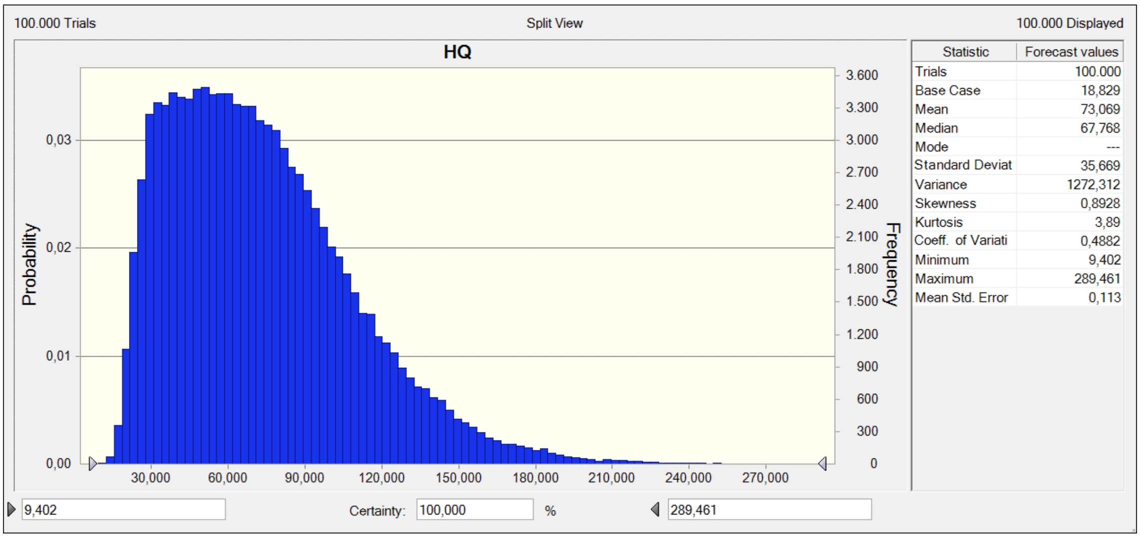
Figure 5.37. Aggregate chronic-toxic risk results of the probabilistic approach for the population with 10,000 people



Statistic	Forecast values
Trials	10.000
Base Case	3,25E-03
Mean	2,20E-02
Median	1,95E-02
Mode	---
Standard Deviat	1,25E-02
Variance	1,57E-04
Skewness	1,29
Kurtosis	5,52
Coeff. of Variati	0,5691
Minimum	2,84E-03
Maximum	1,15E-01
Mean Std. Error	1,25E-04

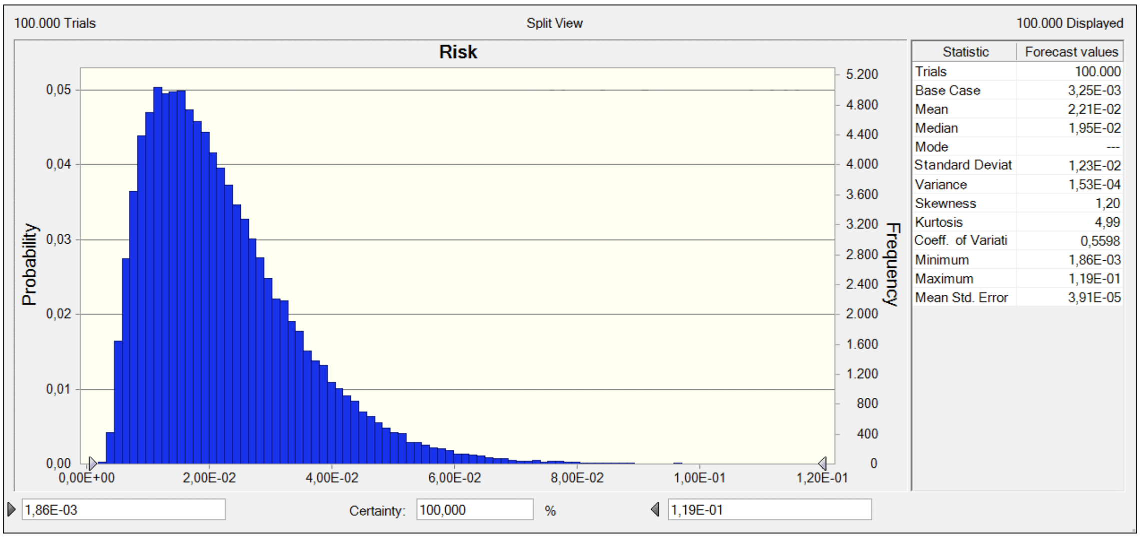
2,84E-03 Certainty: 99,99 % 1,15E-01

Figure 5.38. Aggregate carcinogenic risk results of the probabilistic approach for the population with 10,000 people.



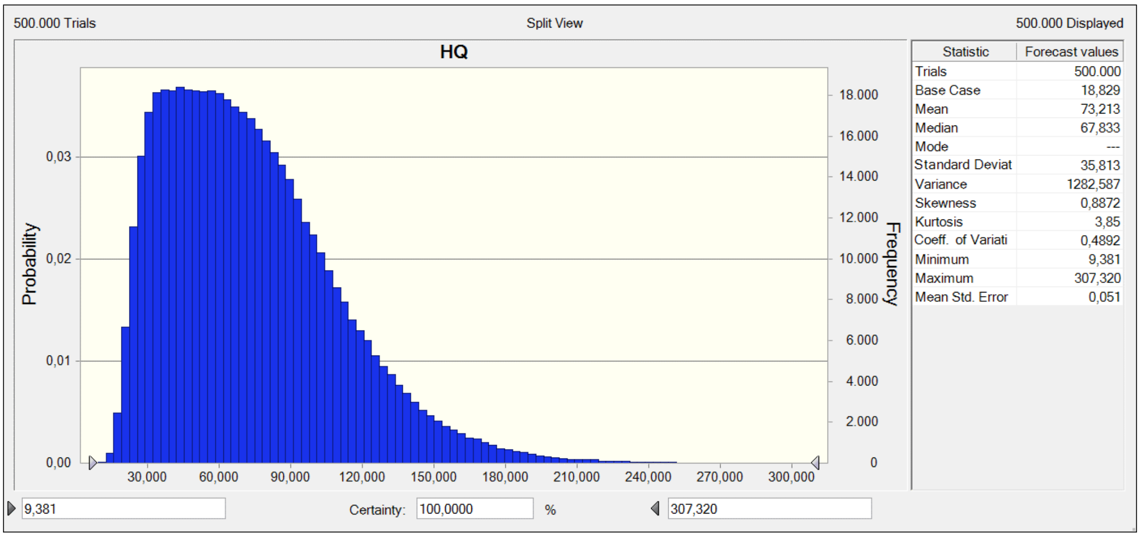
Statistic	Forecast values
Trials	100.000
Base Case	18,829
Mean	73,069
Median	67,768
Mode	---
Standard Deviat	35,669
Variance	1272,312
Skewness	0,8928
Kurtosis	3,89
Coeff. of Variati	0,4882
Minimum	9,402
Maximum	289,461
Mean Std. Error	0,113

Figure 5.39. Aggregate chronic-toxic risk results of the probabilistic approach for the population with 100,000 people



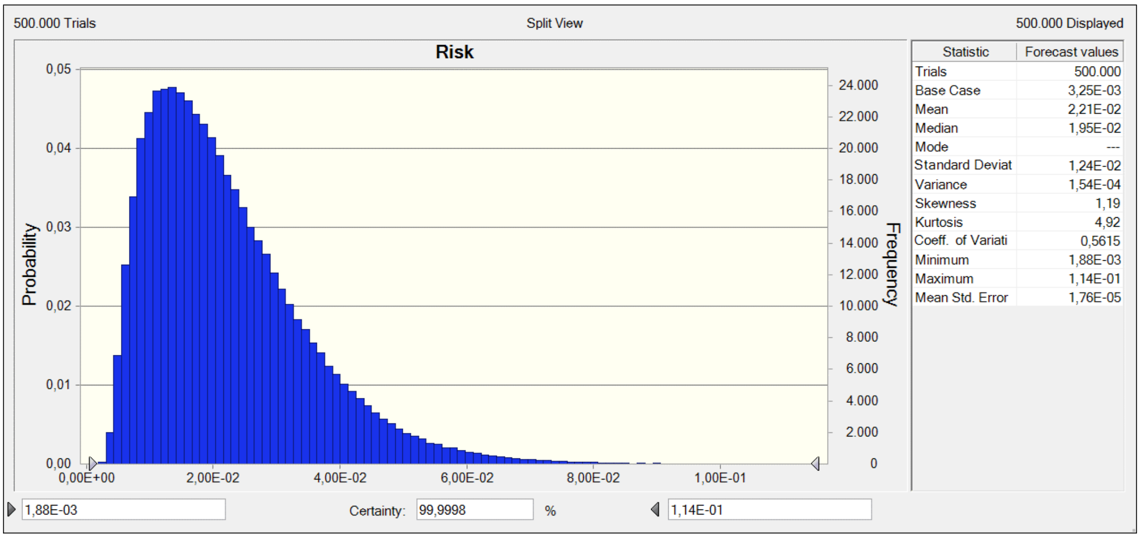
Statistic	Forecast values
Trials	100.000
Base Case	3,25E-03
Mean	2,21E-02
Median	1,95E-02
Mode	---
Standard Deviat	1,23E-02
Variance	1,53E-04
Skewness	1,20
Kurtosis	4,99
Coeff. of Variati	0,5598
Minimum	1,86E-03
Maximum	1,19E-01
Mean Std. Error	3,91E-05

Figure 5.40. Aggregate carcinogenic risk results of the probabilistic approach for the population with 100,000 people



Statistic	Forecast values
Trials	500.000
Base Case	18,829
Mean	73,213
Median	67,833
Mode	---
Standard Deviat	35,813
Variance	1282,587
Skewness	0,8872
Kurtosis	3,85
Coeff. of Variati	0,4892
Minimum	9,381
Maximum	307,320
Mean Std. Error	0,051

Figure 5.41. Aggregate chronic-toxic risk results of the probabilistic approach for the population with 500,000 people



Statistic	Forecast values
Trials	500.000
Base Case	3,25E-03
Mean	2,21E-02
Median	1,95E-02
Mode	---
Standard Deviat	1,24E-02
Variance	1,54E-04
Skewness	1,19
Kurtosis	4,92
Coeff. of Variati	0,5615
Minimum	1,88E-03
Maximum	1,14E-01
Mean Std. Error	1,76E-05

Figure 5.42. Aggregate carcinogenic risk results of the probabilistic approach for the population with 500,000 people

5.4. A Scenario for only the Simav Plain

A more realistic scenario based on agricultural data for only the Simav Plain is presented in this section. Two different approaches (deterministic and probabilistic approach) were formed to assess point-estimate and population health risks.

5.4.1. Deterministic Approach for the Simav Plain

Non-carcinogenic and carcinogenic risks were calculated to estimate the total arsenic exposure by consumption of only the foodstuff cultivated in the Simav Plain.

For non-carcinogenic risk, all plant species except wheat had HQs lower than the threshold limit. Aggregate non-carcinogenic risk was found as 19.3, and wheat constituted almost 91% of the aggregate non-carcinogenic risk.

For carcinogenic risk assessment, four species other than garlic had significant risk levels. Garlic still had a considerable risk level but a low consumption rate which causes lower risk value compared to the other four species. Aggregate carcinogenic risk was 7.29×10^{-3} and signified an important risk level. Table 5.14 shows risk assessment results of the deterministic approach for the Simav Plain.

Table 5.14. Risk Assessment Results for the Simav Plain Obtained via Deterministic Approach

Plant Species	CDI mg/kg-day	HQ	Plant Species	CDI mg/kg-day	Risk
Bean	2.75×10^{-4}	0.91	**Bean**	1.93×10^{-4}	3.46×10^{-4}
Corn	9.43×10^{-5}	0.35	**Corn**	6.60×10^{-5}	1.34×10^{-4}
Garlic	2.82×10^{-5}	0.09	**Garlic**	1.98×10^{-5}	3.56×10^{-5}
Sunflower	1.02×10^{-4}	0.34	**Sunflower**	7.16×10^{-5}	1.29×10^{-4}
Wheat	5.28×10^{-3}	17.59	**Wheat**	3.70×10^{-3}	6.65×10^{-3}
Aggregate HQ	5.78×10^{-3}	19.30	**Aggregate Risk**	4.05×10^{-3}	7.29×10^{-3}

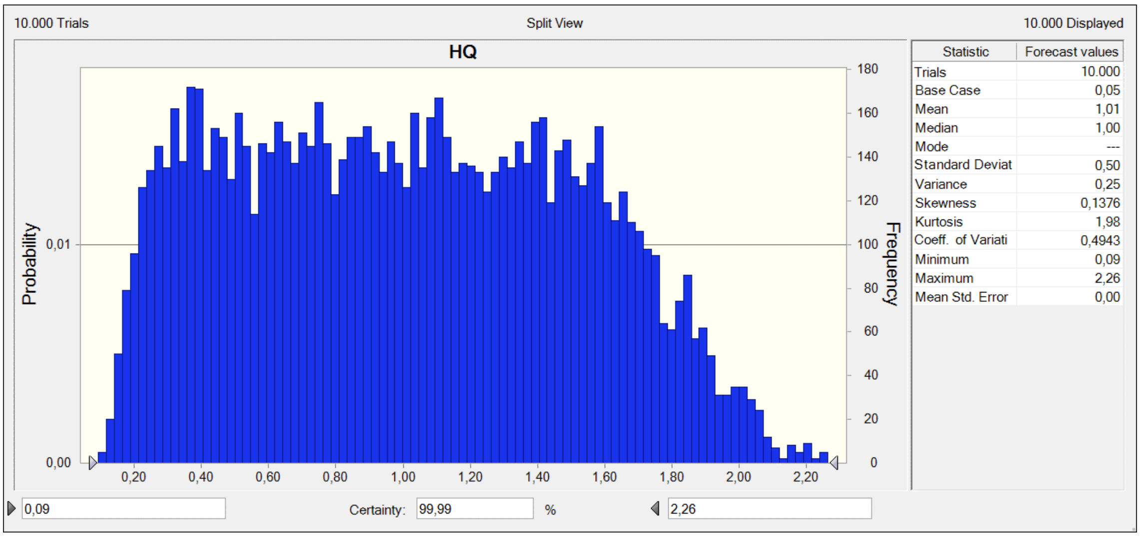
5.4.2. Probabilistic Approach for the Simav Plain

Non-carcinogenic and carcinogenic risks for every plant variety cultivated in the Simav Plain were calculated by using Monte Carlo Simulation. Bioconcentration factors, consumption rates, background As concentrations, exposure duration, fraction of plants ingested from contaminated source, and body weights were fitted a probability distribution. Soil arsenic concentrations were fitted a logistic distribution and ranged between 25.7 and 77.7 mg/kg for the plants with less than one meter root depth. For the plant species with one meter or more root depth, soil arsenic concentrations were fitted a lognormal distribution and ranged between 21.8 and 84.5 mg/kg. Body weights were fitted a normal distribution which ranges between 62.8 and 77.8 kg. All input distributions can be seen in the Appendix A. Calculated non-carcinogenic and carcinogenic risk values are presented in the following sections.

5.4.2.1. Bean

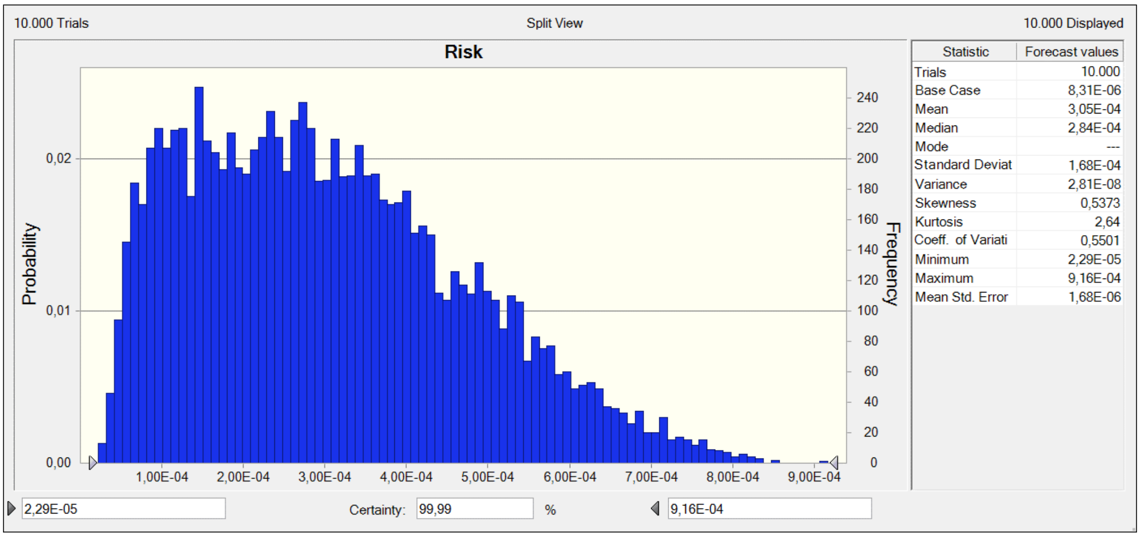
Consumption rate of the Bean was fit a uniform distribution and ranged between 7.2 g/day and 9.6 g/day. Background arsenic concentration also was fit a uniform distribution and varied between 20 and 427 µg/kg. The minimum non-carcinogenic risk was 0.09 while the maximum was 2.26. Five percentile and ninety-five values of the non-carcinogenic risk which represent most plausible outcomes in the population were 0.26 and 1.83 respectively. The mean non-carcinogenic risk was found 1.01 and equal to threshold value. The frequency histogram and descriptive statistics are presented in the Figure 5.43.

Carcinogenic risk of the Bean cultivated in the Simav Plain ranged between 2.3×10^{-5} and 9.2×10^{-4}. The mean carcinogenic risk was found 3×10^{-4}. Five and ninety-five percentile values of the carcinogenic risk were found 7.3×10^{-5} and 6.1×10^{-4} respectively. Skewness was found 0.54 and showed carcinogenic risk values tend to be lower than the mean carcinogenic risk. The frequency histogram and descriptive statistics are presented in the Figure 5.44.



Statistic	Forecast values
Trials	10.000
Base Case	0,05
Mean	1,01
Median	1,00
Mode	---
Standard Deviat	0,50
Variance	0,25
Skewness	0,1376
Kurtosis	1,98
Coeff. of Variati	0,4943
Minimum	0,09
Maximum	2,26
Mean Std. Error	0,00

Figure 5.43. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the Bean



Statistic	Forecast values
Trials	10.000
Base Case	8,31E-06
Mean	3,05E-04
Median	2,84E-04
Mode	---
Standard Deviat	1,68E-04
Variance	2,81E-08
Skewness	0,5373
Kurtosis	2,64
Coeff. of Variati	0,5501
Minimum	2,29E-05
Maximum	9,16E-04
Mean Std. Error	1,68E-06

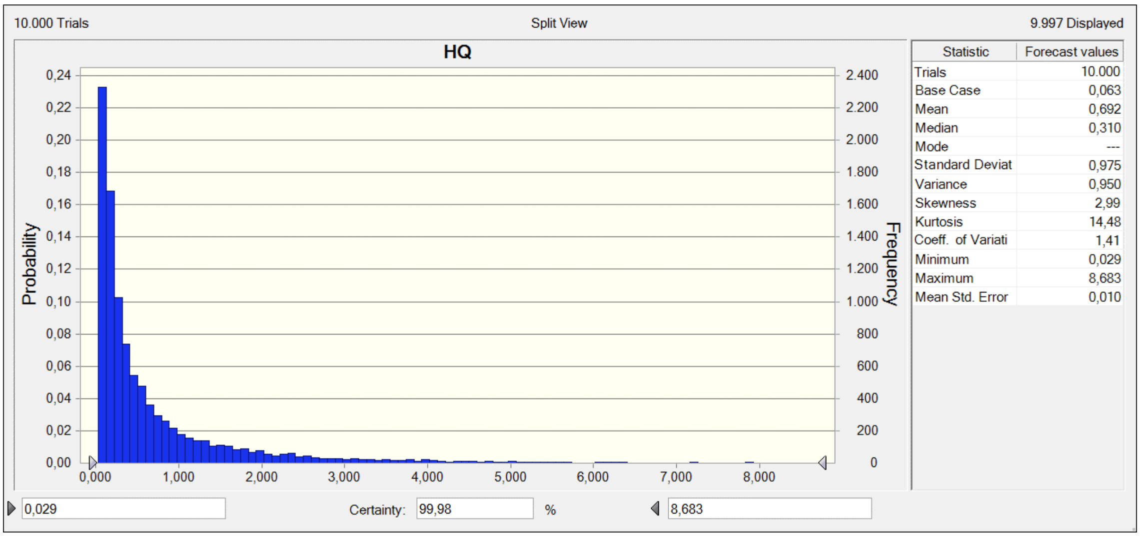
2,29E-05 Certainty: 99,99 % 9,16E-04

Figure 5.44. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the Bean

5.4.2.2. Corn

Bioconcentration factor of corn was fit a lognormal distribution and ranged between 0.00042 and 0.06. Consumption rate was fit a uniform distribution. Consumption rates of corn varied between 40 and 64 g/day. Non-carcinogenic risks were estimated between 0.03 and 8.7. The mean non-carcinogenic risk was found 0.69 and stayed under the threshold limit. Five and ninety-five percentiles of the non-carcinogenic risk were 0.07 and 2.67. Skewness was found 2.99 and showed non-carcinogenic risks between the minimum and the mean non-carcinogenic risks are more possible to occur. The frequency histogram and descriptive statistics of the non-carcinogenic risk assessment are presented in the Figure 5.45.

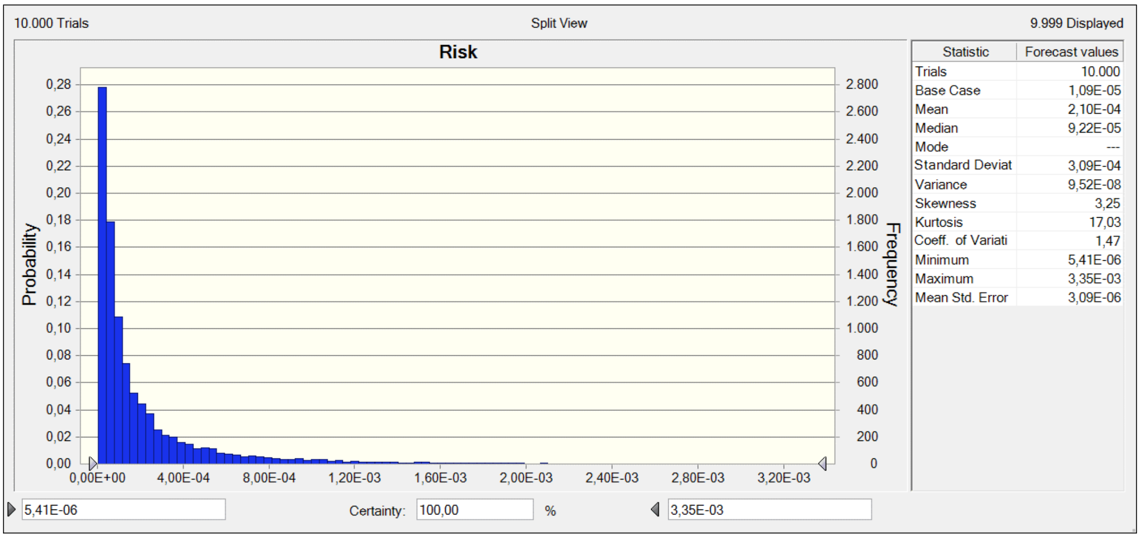
Carcinogenic risk was ranged between 5.4×10^{-6} and 3.4×10^{-3}. The mean carcinogenic risk was 2.1×10^{-4} and the median was 9.2×10^{-5}. Five and ninety-five percentiles of the carcinogenic risk were 1.8×10^{-5} and 8.4×10^{-4}. The frequency histogram and descriptive statistics of the carcinogenic risk assessment are presented in the Figure 5.46.



Statistic	Forecast values
Trials	10.000
Base Case	0,063
Mean	0,692
Median	0,310
Mode	---
Standard Deviat	0,975
Variance	0,950
Skewness	2,99
Kurtosis	14,48
Coeff. of Variati	1,41
Minimum	0,029
Maximum	8,683
Mean Std. Error	0,010

0,029 Certainty: 99,98 % 8,683

Figure 5.45. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of corn



Statistic	Forecast values
Trials	10.000
Base Case	1,09E-05
Mean	2,10E-04
Median	9,22E-05
Mode	---
Standard Deviat	3,09E-04
Variance	9,52E-08
Skewness	3,25
Kurtosis	17,03
Coeff. of Variati	1,47
Minimum	5,41E-06
Maximum	3,35E-03
Mean Std. Error	3,09E-06

5,41E-06 Certainty: 100,00 % 3,35E-03

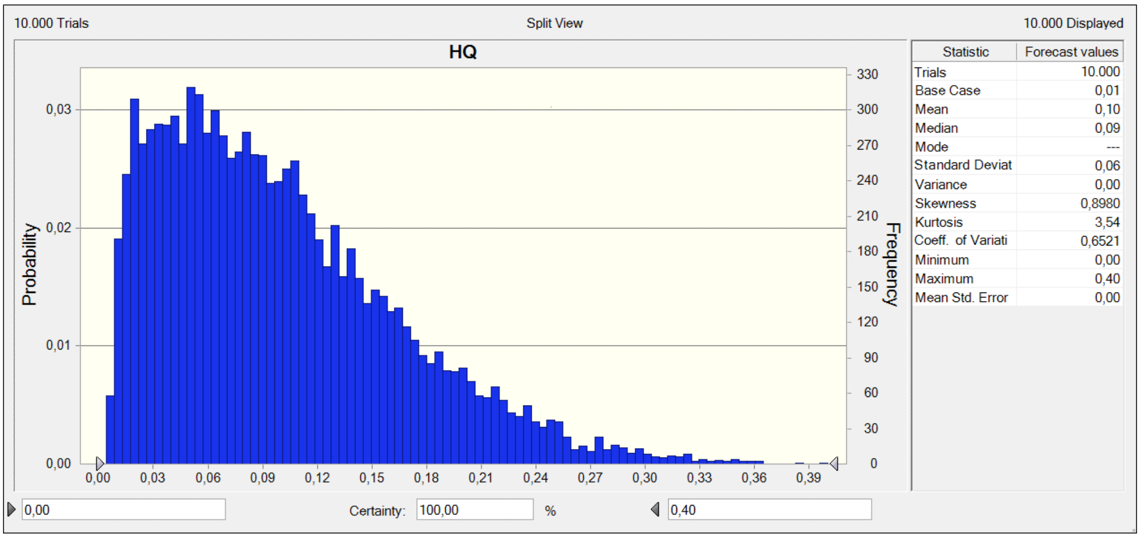
Figure 5.46. The frequency histogram and descriptive statistics of carcinogenic risk assessment of corn

5.4.2.3. Garlic

Bioconcentration factor data of garlic was fit a uniform distribution and varied between 0.022 and 0.049. Consumption rates were fit a uniform distribution. The minimum consumption rate was 2.14 g/day while maximum was 2.65 g/day. Background arsenic concentrations were also fit a uniform distribution and ranged between 8.50 and 19.3 µg/kg. The minimum non-carcinogenic risk was 0.00 and maximum was 0.40. The mean non-carcinogenic risk was found 0.10 while median was

0.09. The frequency histogram and descriptive statistics of the non-carcinogenic risk assessment are presented in the Figure 5.47.

The mean carcinogenic risk and the median were 3×10^{-5} and 2.5×10^{-5} respectively. The carcinogenic risks ranged between 9.3×10^{-7} and 1.45×10^{-4}. Five and ninety-five percentile values of the frequency histogram were 5.1×10^{-6} and 7.1×10^{-5} respectively. The frequency histogram and descriptive statistics of the carcinogenic risk assessment are presented in the Figure 5.48.



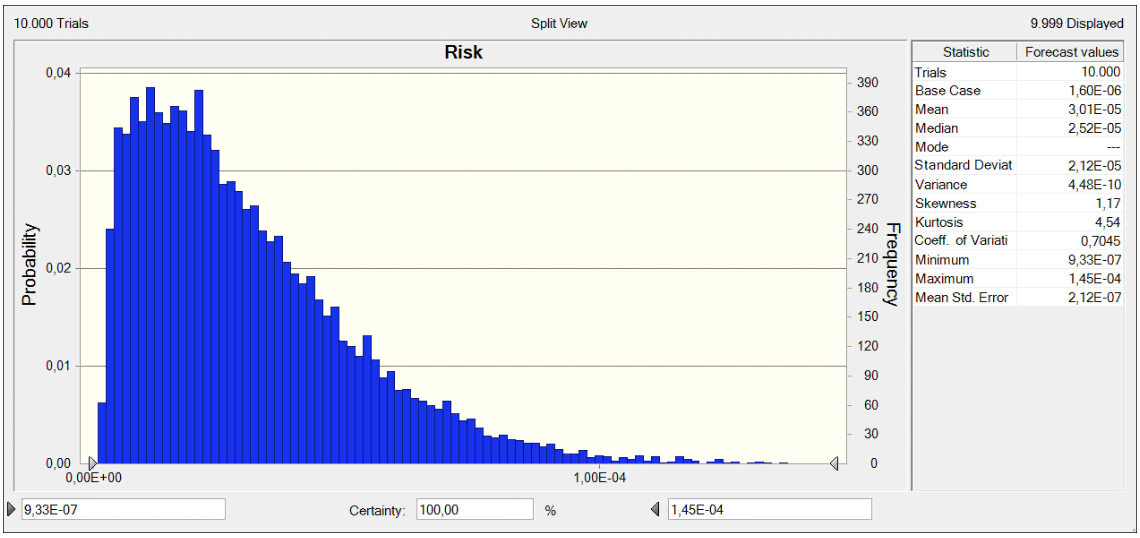
Statistic	Forecast values
Trials	10.000
Base Case	0,01
Mean	0,10
Median	0,09
Mode	---
Standard Deviat	0,06
Variance	0,00
Skewness	0,8980
Kurtosis	3,54
Coeff. of Variati	0,6521
Minimum	0,00
Maximum	0,40
Mean Std. Error	0,00

0,00

Certainty: 100,00 %

0,40

Figure 5.47. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of garlic



Statistic	Forecast values
Trials	10.000
Base Case	1,60E-06
Mean	3,01E-05
Median	2,52E-05
Mode	---
Standard Deviat	2,12E-05
Variance	4,48E-10
Skewness	1,17
Kurtosis	4,54
Coeff. of Variati	0,7045
Minimum	9,33E-07
Maximum	1,45E-04
Mean Std. Error	2,12E-07

9,33E-07

Certainty: 100,00 %

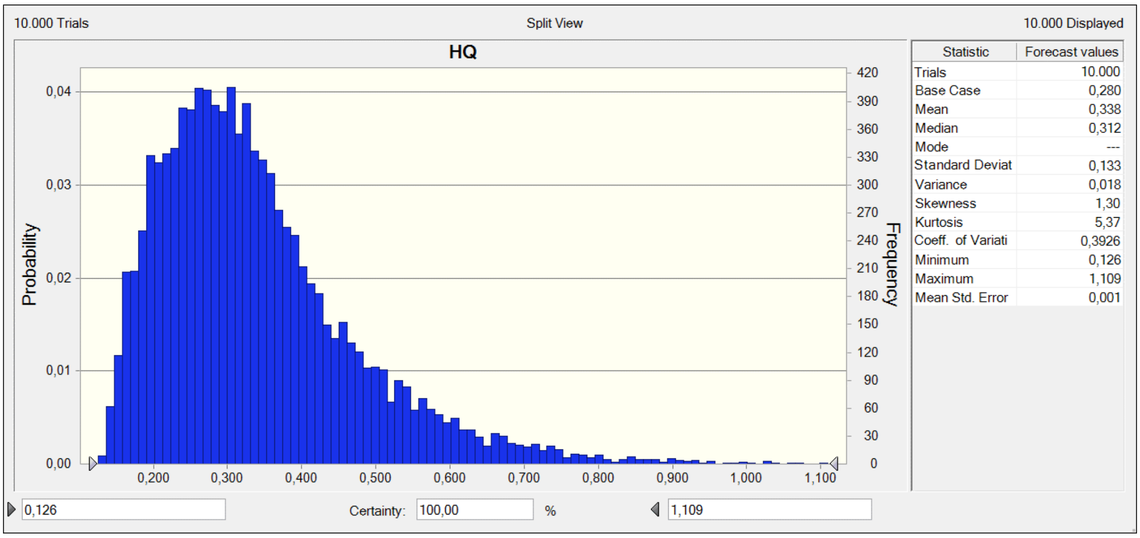
1,45E-04

Figure 5.48. The frequency histogram and descriptive statistics of carcinogenic risk assessment of garlic

5.4.2.4. Sunflower

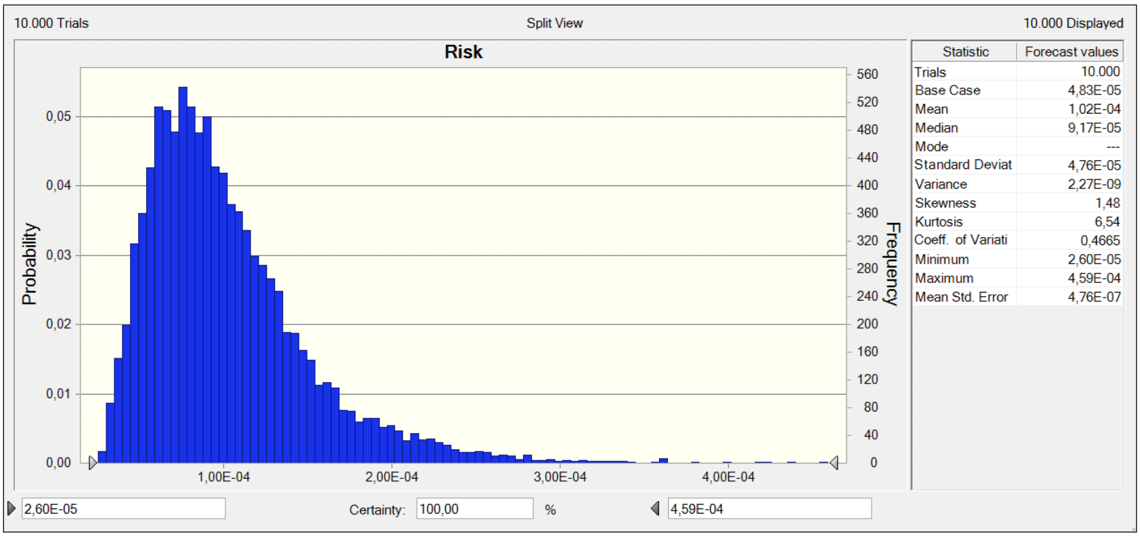
Consumption rate data of the sunflower seed was fit a uniform distribution which ranged between 42.5 and 99.8 g/day. The non-carcinogenic risk varied between 0.13 and 1.11. The mean and the median non-carcinogenic risk were 0.34 and 0.31 respectively. Five and ninety-five percentiles of the non-carcinogenic risk were 0.17 and 0.60. The frequency histogram and descriptive statistics of the non-carcinogenic risk assessment are presented in the Figure 5.49.

The carcinogenic risk of the sunflower cultivated in the Simav Plain varied between 2.6×10^{-5} and 4.6×10^{-4}. The mean and the median carcinogenic risks were found 1.0×10^{-4} and 9.2×10^{-5} respectively. Five and ninety-five percentiles of the carcinogenic risk were 4.6×10^{-5} and 1.95×10^{-4}. The frequency histogram and descriptive statistics of the non-carcinogenic risk assessment are presented in the Figure 5.50.



Statistic	Forecast values
Trials	10.000
Base Case	0,280
Mean	0,338
Median	0,312
Mode	---
Standard Deviat	0,133
Variance	0,018
Skewness	1,30
Kurtosis	5,37
Coeff. of Variati	0,3926
Minimum	0,126
Maximum	1,109
Mean Std. Error	0,001

Figure 5.49. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of the sunflower



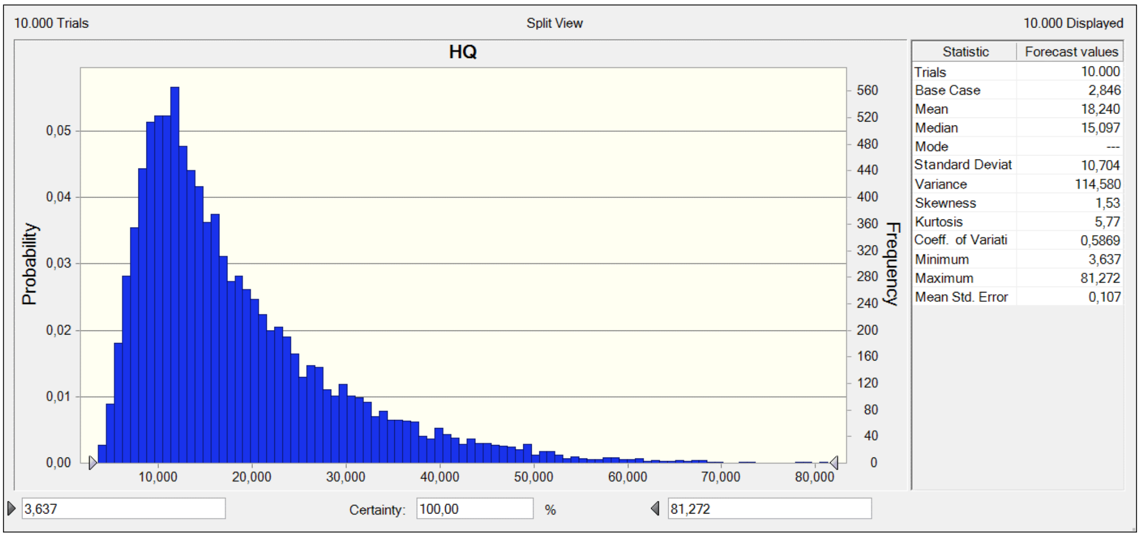
Statistic	Forecast values
Trials	10.000
Base Case	4,83E-05
Mean	1,02E-04
Median	9,17E-05
Mode	---
Standard Deviat	4,76E-05
Variance	2,27E-09
Skewness	1,48
Kurtosis	6,54
Coeff. of Variati	0,4665
Minimum	2,60E-05
Maximum	4,59E-04
Mean Std. Error	4,76E-07

Figure 5.50. The frequency histogram and descriptive statistics of carcinogenic risk assessment of the sunflower

5.4.2.5. Wheat

Bioconcentration factor data of wheat was fit a beta distribution and ranged between 0.0068 and 0.040. Consumption rates were fit a unifrom distribution and varied between 549 and 628 g/day. Background arsenic concentrations also were fit a uniform distribution and ranged between 123 and 407 µg/kg. The minimum non-carcinogenic risk was 3.64 and the maximum was 81.3. The mean and the median non-carcinogenic risks were 18.2 and 15.1 respectively. Five and ninety-five percentiles of the non-carcinogenic risks were found 6.82 and 40.3 respectively. The frequency histogram and descriptive statistics of the non-carcinogenic risk assessment are presented in the Figure 5.51.

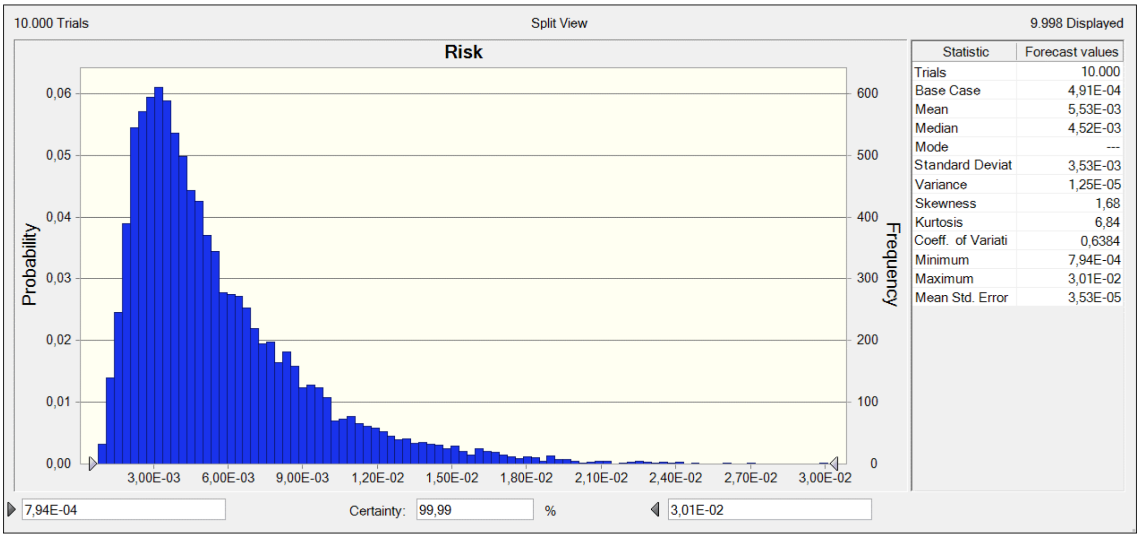
The carcinogenic risk was estimated between 7.9×10^{-4} and 3.0×10^{-2}. The mean and the median carcinogenic risk were 5.5×10^{-3} and 4.5×10^{-3} respectively. Five and ninety-five percentiles were 1.8×10^{-3} and 1.3×10^{-2}. The frequency histogram and descriptive statistics of the carcinogenic risk assessment are presented in the Figure 5.52.



Statistic	Forecast values
Trials	10.000
Base Case	2,846
Mean	18,240
Median	15,097
Mode	---
Standard Deviat	10,704
Variance	114,580
Skewness	1,53
Kurtosis	5,77
Coeff. of Variati	0,5869
Minimum	3,637
Maximum	81,272
Mean Std. Error	0,107

3,637 Certainty: 100,00 % 81,272

Figure 5.51. The frequency histogram and descriptive statistics of non-carcinogenic risk assessment of wheat



Statistic	Forecast values
Trials	10.000
Base Case	4,91E-04
Mean	5,53E-03
Median	4,52E-03
Mode	---
Standard Deviat	3,53E-03
Variance	1,25E-05
Skewness	1,68
Kurtosis	6,84
Coeff. of Variati	0,6384
Minimum	7,94E-04
Maximum	3,01E-02
Mean Std. Error	3,53E-05

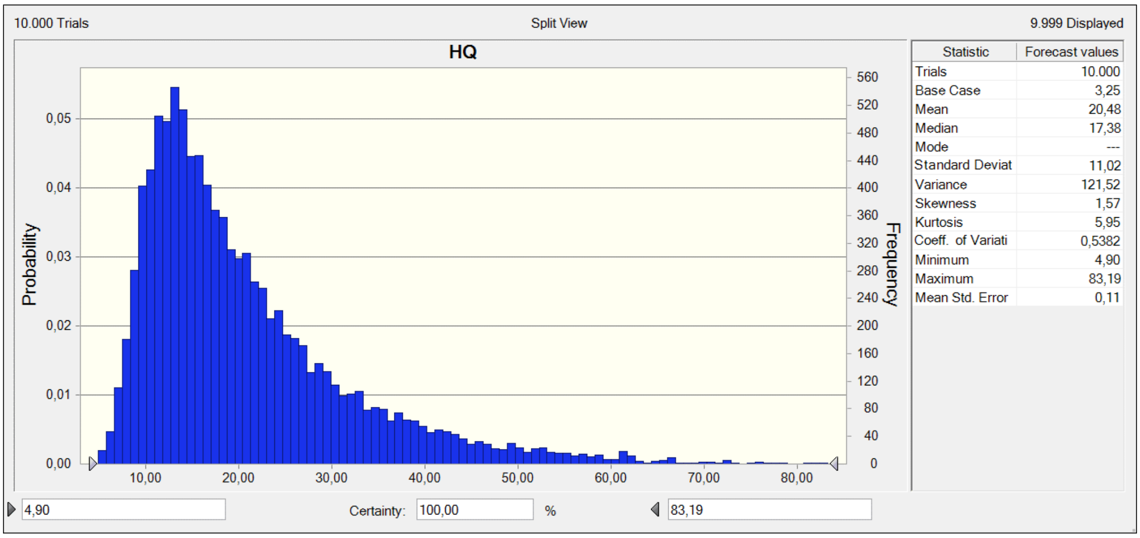
7,94E-04 Certainty: 99,99 % 3,01E-02

Figure 5.52. The frequency histogram and descriptive statistics of carcinogenic risk assessment of wheat

5.4.2.6. Aggregate Risk

Monte Carlo simulation was run 10,000 times to estimate aggregate non-carcinogenic and carcinogenic risks. Aggregate non-carcinogenic risk varied between 4.9 and 83. The mean aggregate chronic-toxic risk was found as 20.5 and median was found as 17.4. Standard deviation was found as 11.0. Figure 5.53 shows the aggregate chronic-toxic risk results for n=10,000. Aggregate carcinogenic risk ranged between 1.64×10^{-3} and 8.55×10^{-2}. The mean aggregate carcinogenic risk was found as 1.70×10^{-2}

and indicated significant risk. Standard deviation was found as 1.35×10^{-2}. Figure 5.54 shows aggregate carcinogenic risk results for n=10,000.



10.000 Trials

Split View

9.999 Displayed

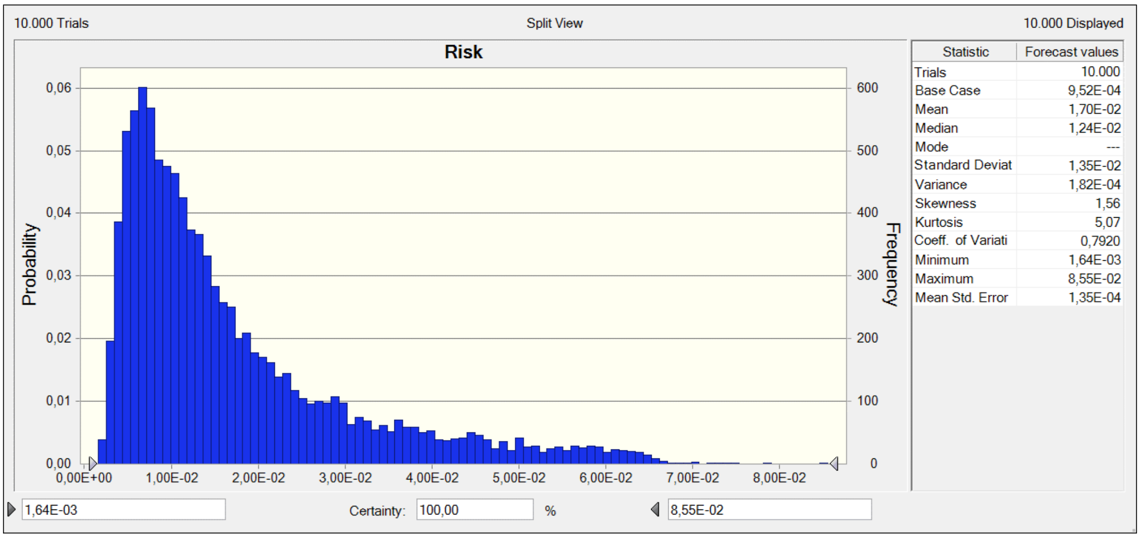
Statistic	Forecast values
Trials	10.000
Base Case	3,25
Mean	20,48
Median	17,38
Mode	---
Standard Deviat	11,02
Variance	121,52
Skewness	1,57
Kurtosis	5,95
Coeff. of Variati	0,5382
Minimum	4,90
Maximum	83,19
Mean Std. Error	0,11

4,90

Certainty: 100,00 %

83,19

Figure 5.53. Aggregate chronic-toxic risk results of the probabilistic approach



10.000 Trials

Split View

10.000 Displayed

Statistic	Forecast values
Trials	10.000
Base Case	9,52E-04
Mean	1,70E-02
Median	1,24E-02
Mode	---
Standard Deviat	1,35E-02
Variance	1,82E-04
Skewness	1,56
Kurtosis	5,07
Coeff. of Variati	0,7920
Minimum	1,64E-03
Maximum	8,55E-02
Mean Std. Error	1,35E-04

1,64E-03

Certainty: 100,00 %

8,55E-02

Figure 5.54. Aggregate carcinogenic risk results of the probabilistic approach

5.5. Sensitivity Analysis

Sensitivity analyzes for the probabilistic approaches were performed to determine the variables that have a significant effect on the risk estimates. Results of the probabilistic approaches for the eighteen plant species for the Simav District and the five plant species cultivated in the Simav Plain were investigated. Consumption ratio from contaminated source, background As concentration, consumption rate, soil As concentrations, body weight, bioconcentration factor, and exposure duration were examined in terms of their contribution to variance.

Sensitivity analysis results of non-carcinogenic risk assessment of the Simav District showed that bioconcentration factor is the most influential variable that affect the results of the non-carcinogenic risk assessment. Consumption ratio from contaminated source followed the BCF, and ranked at the second place. Background arsenic concentrations, consumption rates, soil arsenic concentrations, and body weight do not have a big influence on the results. Table 5.15 shows the sensitivity analysis results for the non-carcinogenic risk assessment of the Simav District.

For the carcinogenic risk assessment of the Simav District most influential factor was determined as bioconcentration factor. The second most influential factor was consumption ratio from the contaminated sources. It should be noted that for some plant species with insufficient BCF data such as bean, cucumber, and sunflower the most important factor was also determined as consumption ratio from the contaminated source. Table 5.16 shows the results of sensitivity analysis results for carcinogenic risk assessment of the Simav District.

Table 5.15. Sensitivity Analysis Results for Non-Carcinogenic Risk Assessment of the Simav District

Plant Species	**Contribution to Variance %**					
	Consumption ratio from contaminated source	**Consumption Rate**	**BW**	**Soil As conc.**	**Background As concentration**	**BCF**
Bean	0.888	0.085	0.015	0.007	0.004	-
Broccoli	0.255	-	0.005	0.168	0.263	0.309
Cabbage	0.723	0.005	0.019	0.014	-	0.239
Carrot	0.303	0.107	0.005	0.098	0.002	0.485
Cauliflower	0.297	-	0.005	0.106	-	0.592
Corn	0.078	0.016	0.003	0.030	-	0.873
Cucumber	0.959	0.020	0.020	-	-	-
Eggplant	0.401	0.010	0.009	0.078	0.002	0.499
Garlic	0.632	0.016	0.007	0.203	-	0.143
Lettuce	0.040	0.003	0.001	0.024	0.017	0.916
Okra	0.716	0.034	0.013	0.014	-	0.222
Onion	0.703	0.025	0.010	0.233	0.002	0.028
Potato	0.787	0.039	0.014	0.006	-	0.153
Radish	0.282	0.006	0.005	0.114	-	0.592
Spinach	0.296	0.005	0.005	0.104	-	0.591
Sunflower	0.098	0.549	0.028	0.326	-	-
Tomato	0.243	0.002	0.005	0.150	0.014	0.586
Wheat	0.248	0.005	0.013	0.244	0.024	0.466

Table 5.16. Sensitivity Analysis Results for Carcinogenic Risk Assessment of the Simav District

Plant Species	Contribution to Variance %						
	Consumption ratio from contaminated source	**Consumption Rate**	**BW**	**Soil As conc.**	**Background As conc.**	**BCF**	**ED**
Bean	0.703	0.063	0.011	0.006	0.004	-	0.212
Broccoli	0.219	-	0.003	0.145	0.225	0.250	0.158
Cabbage	0.603	0.005	0.016	0.012	0.000	0.216	0.150
Carrot	0.282	0.099	0.004	0.090	0.002	0.450	0.074
Cauliflower	0.278	-	0.005	0.098	-	0.557	0.063
Corn	0.075	0.016	0.003	0.028	-	0.846	0.034
Cucumber	0.788	0.013	0.015	-	-	-	0.183
Eggplant	0.346	0.009	0.009	0.069	0.002	0.455	0.110
Garlic	0.555	0.013	0.006	0.170	-	0.122	0.135
Lettuce	0.038	0.003	0.001	0.023	0.016	0.892	0.027
Okra	0.599	0.027	0.009	0.012	-	0.200	0.153
Onion	0.597	0.020	0.008	0.208	0.001	0.026	0.140
Potato	0.655	0.028	0.012	0.006	-	0.137	0.163
Radish	0.259	0.005	0.004	0.100	-	0.559	0.072
Spinach	0.272	0.005	0.004	0.096	-	0.551	0.072
Sunflower	0.070	0.388	0.021	0.251	-	-	0.271
Tomato	0.215	0.002	0.005	0.134	0.013	0.527	0.102
Wheat	0.205	0.004	0.011	0.209	0.020	0.395	0.157

Sensitivity analysis results of non-carcinogenic risk assessment of the Simav Plain showed that bioconcentration factor is the most influental variable for the species such as corn and wheat but it ws consumption ratio from the contaminated source for bean and garlic. Interestingly, unlike BCF or consumption ratio from the contaminated source, consumption rate was determined as the most influential factor for sunflower seeds while exposure duration also contributed to variance as close as consumption rate. Results of the sensitivity analysis for non-carcinogenic risk assessment of the Simav Plain are shown in Table 5.17.

Table 5.17. Sensitivity Analysis Results for Non-Carcinogenic Risk Assessment of the Simav Plain

Plant Species	Contribution to Variance %					
	Consumption ratio from contaminated source	**Consumption Rate**	**BW**	**Soil As conc.**	**Background As conc.**	**BCF**
Bean	0.966	0.024	0.006	-	0.003	-
Corn	0.150	0.016	0.002	0.032	-	0.801
Garlic	0.750	0.008	0.004	0.117	-	0.121
Sunflower	0.172	0.489	0.022	0.317	-	-
Wheat	0.341	0.004	0.007	0.199	0.033	0.416

For carcinogenic risk assessment of the Simav Plain, similar results were obtained. Bean and garlic were the species which have consumption ratio from the contaminated source as the most influential factor. For sunflower seeds, consumption rate was the most important variable, while for corn and wheat bioconcentration factor was the most influential variable. Table 5.18 shows the results of the sensitivity analysis for carcinogenic risk assessment of the Simav Plain.

Table 5.18. Sensitivity Analysis Results for Carcinogenic Risk Assessment of the Simav Plain

Plant Species	Contribution to Variance %						
	Consumption ratio from contaminated source	**Consumption Rate**	**BW**	**Soil As conc.**	**Background As conc.**	**BCF**	**ED**
Bean	0.828	0.020	0.005	-	0.003	-	0.143
Corn	0.146	0.015	0.001	0.030	-	0.771	0.037
Garlic	0.683	0.007	0.003	0.102	-	0.104	0.101
Sunflower	0.119	0.341	0.013	0.224	-	-	0.303
Wheat	0.285	0.004	0.006	0.169	0.030	0.346	0.160

In conclusion, sensitivity analysis results can be interpreted that bioconcentration factors and consumption ratio from the contaminated source are the most influential factors that affect the etimated risk levels. Therefore, to have sufficient BCF data is important and may seriously affect the risk assessment, and risk management strategies. Nevertheless, the results indicate that reduction in consumption from contaminated sources may be the most effective solution to mitigate the risks.

5.6. Comparison of the Estimates with the Literature

Among all the deterministic approaches the highest non-carcinogenic and carcinogenic risks were found for upper-bound estimation of Scenario 1 conducted for whole Simav District. For the scenario, aggregate non-carcinogenic risk was 271 which is 135 times the significant non-carcinogenic risk limit, and aggregate carcinogenic risk was 1.21×10^{-1} which is at least a thousand times the significant carcinogenic risk limit. The lowest non-carcinogenic and carcinogenic risks was observed for the lower-bound estimation of Scenario 3 for whole Simav District among the deterministic approaches. In the scenario, aggregate non-carcinogenic risk was 9.74 and aggregate carcinogenic risk was 2.86×10^{-3}. For the scenario only conducted for Simav Plain, aggregate carcinogenic risk was 7.29×10^{-3} and aggregate non-carcinogenic risk was 19.3.

In the probabilistic approach for the whole Simav District, wheat, tomato, onion, eggplant, and potato were the species that may constitute important risk for human health. Among them, wheat had the highest non-carcinogenic and carcinogenic risks. Fifth and ninety-fifth percentile values of non-carcinogenic risk for wheat were 6.87 and 49.4, respectively. For carcinogenic risk, 5th and 95th percentiles were found as 1.81×10^{-3} and 1.58×10^{-2}, respectively. In the probabilistic approach of the scenario which was conducted only for the Simav Plain, 5th and 95th percentiles of non-carcinogenic risks for wheat were found as 6.82 and 40.3, respectively. Fifth and ninety-fifth percentiles of carcinogenic risk were 1.8×10^{-3} and 1.3×10^{-2} for wheat.

There are a limited number of studies about arsenic transfer from soil to plants in the literature. Alam et al. (2016) investigatd soil, plant, and groundwater relationship in Sahibganj, India. Groundwater arsenic concentrations ranged between 23 to 176 µg/L (at least 2.3 times the WHO limit). Soil arsenic concentrations varied between approximately 4 to 7 mg/kg. However, available soil arsenic concentrations for plants were found between 0.06 to 1.58 mg/kg. In the study twenty-five different plants were examined. Arsenic concentrations in the edible parts of the plants varied between 0.01 to 0.21 mg/kg. Similar to this study, the highest arsenic concentration was found in wheat as 0.21 mg/kg. Some of the arsenic concentrations in the edible parts of the plants, which also was examined in the study were found as follows; Garlic 0.18 mg/kg, Corn 0.13 mg/kg, Spinach 0.17 mg/kg, Tomato 0.05 mg/kg, Cucumber 0.10 mg/kg, Eggplant 0.12 mg/kg, Okra 0.04 mg/kg, Potato 0.10 mg/kg, Onion 0.07 mg/kg, and Radish 0.11 mg/kg. Arsenic concentrations found in the study were much lower compared to arsenic concentrations found in this study. Main reasons of that may be (1) insufficient BCF data and (2) lack of knowledge about available soil arsenic concentrations in Simav. Since the entire arsenic in soil does not transfer from soil to plants, some errors in the calculation of plant concentrations are inevitable. Deterministic risk assessment results of the study are as follows; Wheat 2.18, Corn 0.53, Spinach 0.24, Onion 0.20, Tomato 0.09, Cucumber 0.02, Eggplant 0.06, Okra 0.02, Potato 0.47, Radish 0.03, and Garlic 0.12. Even if the plants concentration were lower, the results are very similar to results obtained in the central tendency and lower-bound estimations in this study. However, it should be noted that unlike the study by Alam et al. (2016), estimations in the present study, consumption from contaminated and uncontaminated sources were seperately considered.

In the study conducted by Ahmed et al. (2016), wheat, eggplant, bean, potato, tomato, and onion were examined on the account of inorganic arsenic concenrations and estimated daily intake. Inorganic arsenic concentrations ranged between 0.19 to 0.33 mg/kg. Among the species, none of the estimated daily intake values exceeded tolerable daily intake limit (2.1 µg/kg-day). Again, plant arsenic concentrations were much lower compared to this study. Rehman et al. (2016) calculated incremental lifetime cancer risk (ILTCR) and hazard quotients deterministically for eggplant and tomato. Hazard quotient for tomato and eggplant was 0.11 and 0.01, respectively. ILCTR for eggplant and tomato was 6.63×10^{-6} and 5.10×10^{-5}, respectively. Incremental lifetime cancer risk values are very close to 5th percentile values of the probabilistic approach for the Simav district. However, HQs are lower compared to this study probably due to low plant arsenic concentrations which are 0.13 mg/kg for tomato and 1 mg/kg for eggplant. Jiang et al. (2015) found average arsenic concentrations in the plants as follows; Lettuce 0.013 mg/kg, Cucumber 0.013 mg/kg, Eggplant 0.007 mg/kg, and Tomato 0.007 mg/kg. In the study, aggregated non-carcinogenic and carcinogenic risk calculated deterministically for the foodstuffs included vegetables, meats, fruits, and seafoods. For the adults, aggregate non-carcinogenic risk ranged between 0.78 to 1.04, which are much lower compared to this study. Aggregate carcinogenic risk for adults were much more comparable to this study and varied between 3.27×10^{-4} and 1.60×10^{-4}. Gunduz et al. (2010) have investigated the cancer risk via groundwater of Simav and found the possibility of cancer as 4.95×10^{-3}. Results of this study showed that arsenic exposure via consumption of plants may be important as arsenic exposure via groundwater. Also, non-carcinogenic and carcinogenic risks were found much higher compared to arsenic risk assessment studies via foodstuff in the literature and showed the necessity of the future studies and risk management strategies.

5.7. Limitations of the Study

There are some limitations of this study because the estimations were based on measured soil arsenic concentrations and data collected from the literature. The main limitations are as follows. (1) Plant concentrations were estimated from the measured soil concentrations using BCF values collected from the literature, however, their availability were limited some of the subject plants. Only eleven journal articles that reported BCF values for the subject plants could be found. The number of identified BCF values was as low as one (bean, cucumber, and sunflower), two (garlic and onion), three (carrot and okra), and four (broccoli) while the remainder had at least five with corn, lettuce, and wheat the highest number (n=19, 20, and 21, respectively). As a result, variabilty in the calculated arsenic concentrations in the subject plants are limited for some plants by the variation in the soil concentrations. (2) The second limitation was the scarcity of specific toxicity data about arsenic on the subject plants. The estimated plant arsenic concentrations may reach extreme levels depending on the level of the measured soil concentrations and the available BCF values, which may not be plausible due to the toxicity of arsenic. However, the data were very limited. Therefore, the lower bound value of a suggested general range (5 mg/kg) was used as the maximum concentration that a plant may contain. (3) There is also a lack of data about background arsenic concentrations of certain species such as corn, okra, and sunflower seed, while some species such as potato have wide ranges. (4) Bioavailability of arsenic could only be found for three of the 18 subject species (carrot, lettuce, and radish), forcing the assumption of 100% bioavailability for the rest. (5) The consumption database of the TSI was limited, not allowing differentiation of fresh and procesesed consumption rates, which was very important for tomatoes because its consumption rates as salsa and paste forms are high in the Turkish population as in fresh produce. The other important plant was wheat because it is the main substinence crop for the Turkish population consumed in various processed forms. Since their comsumption rates are high (308 and 593 g/day for tomatoes and wheat, respectively) even low concentration levels were translated into considerable or sinificant health risk levels. In consequence, contribution to the estimated aggregate risks were dominated by tomatoes and wheat. (6) Lastly, the soil concentrations measured by Gündüz et al. (2012) are at the high end of the levels reported in the literature, which probably may be the main factor in estimating such high plant concentrations and health risks associated with their consumption. Also, speciated or water soluble arsenic concentrations in the soil were not available in the measurements made by Gündüz et al. (2012). Since the plants only absorb the water soluble arsenic from their roots, it probably caused over estimation of the plant arsenic concentrations. While cooking may result in leaching of arsenic from plant to cooking water, it may not occur depending on the level of water contamination.. The effects of processing and cooking on the exposed concentations cold not be considered in thi study. Hence, these issues contributed into the uncertainty in the estimations.

CHAPTER 6

CONCLUSIONS

6.1. Conclusions of the Study

An exposure – risk assessment was conducted for the Simav District and the Simav Plain, where waters and soil are contaminated with arsenic from natural sources, for ingestion of edible plants cultivated on the contaminated land. The assessment included both scenario-based point estimates (deterministic approach) and probabilistic population estimates. The edible plants were found as an important source of exposure to arsenic. Point estimates of aggregate chronic-toxic risk for the whole Simav District varied from 9.74 to 271 while aggregate carcinogenic risk levels ranged between 2.86×10-3 and 1.21×10-1. The worst-case scenario was that all produce were assumed to be consumed in the Simav District with the use of values of involved variables that would result in the highest plausible carcinogenic and chronic-toxic risk levels (the 90th percentile). In the risk assessment conducted for the Simav Plain only the five plant species cultivated on the Plain (bean, corn, garlic, sunflower, wheat) were considered. Aggregate chronic-toxic risk was 19.30 and the carcinogenic risk was 7.29×10-3 in the deterministic approach. Wheat was found as the foodstuff with the most associated chronic-toxic risk in all deterministic scenarios ranging between 4.50 and 91.2 which are at least 2.25-folds higher than the significant non-carcinogenic risk threshold of 2. The carcinogenic risk values of wheat were found between 1.32×10-3 and 4.05×10-2, which are higher than the acceptable risk level of 10-4. Wheat was followed by tomatoes probably because both have very high consumption rates in Turkey, which in contrast may also be the reason for the lowest chronic-toxic and carcinogenic risks estimated for broccoli and cauliflower due to their low consumption rates.

The 5th and 95th percentiles were estimated as 27 and 140 for aggregate non-carcinogenic risk, and as 7.1×10-3 and 4.6×10-2 for aggregate carcinogenic risk, respectively for the whole Simav District, with all three sizes of Monte Carlo simulation showing that n=10,000 is sufficient for the probabilistic approach. In the probabilistic approach conducted for the Simav Plain, aggregate chronic-toxic risk ranged between 4.9 to 83.2. The aggregate carcinogenic risk for the Simav Plain varied between

1.64×10-3 and 8.55×10-2. Wheat was found to be the foodstuff with the highest contribution to the aggregate risk, probably because of its high consumption rate. Potato, onion, cucumber, eggplant, corn, and cabbage were the other species with significant risk, whereas garlic, cauliflower, and broccoli were the species with non-carcinogenic risk lower than the threshold. However, carcinogenic risk assessment results showed that consumption of all of the plants are associated with a degree of carcinogenic risk above the acceptable level.

6.2. Recommendations for Risk Management

The results of this study have shown that risk management strategies are needed in the study area to protect public health. Even in the lower-bound estimation of Scenario-3 which considers only 10% consumption from the plants cultivated in the Simav Plain, aggregate non-carcinogenic and carcinogenic risks are still significant, and risk mitigation strategies are needed. Wheat, tomato, onion, and cucumber are the species with significant carcinogenic and chronic-toxic risks. Therefore, importing these from uncontaminated places would reduce the aggregate risks up to 88%. Since there is no safe level for arsenic, the lowest consumption of produce grown on the plain is recommended.

6.3. Future Studies

The results of this study confirm that arsenic transfer from soil to edible plants could threaten people of Simav, therefore, call for further studies. Future study recommendations presented as follows to improve the knowledge gained from this thesis. Water soluble arsenic concentration in Simav soil and arsenic type in the soil are not known and should be analyzed since the plants only absorb water soluble arsenic from soil. Speciated arsenic concentrations could be determined since toxicity relevant forms are the inorganic species. In addition, the role of irrigation water in plant contamination could be studied. A food consumption survey is recommended to understand eating habits of the local people since the gathered consumption rates were for the geneal Turkish population, not specific to Simav. In the survey, age, body weight, and gender of people, consumed food amount and type, proportion of locally grown and imported foodstuffs, source of water used in cooking need to be determined. After the survey, sampling of the most consumed foodstuffs before and after cooking to analyze arsenic and other potential trace elements is recommended. Analyzing the foodstuff before and after cooking provides a chance to understand leaching of arsenic from foodstuff to water while cooking. Arsenic type in the foodstuff is also important and should be analyzed since in the literature reference dose and slope factor values are only available for inorganic arsenic. If local water is used for cooking it means there is a risk for contamination thus the cooking water also should be analyzed. Finally, a data analysis should be performed to estimate contribution of irrigation water, cooking water, soil to foodstuff arsenic concentrations, which would allow devising of better risk mitigation strategies.

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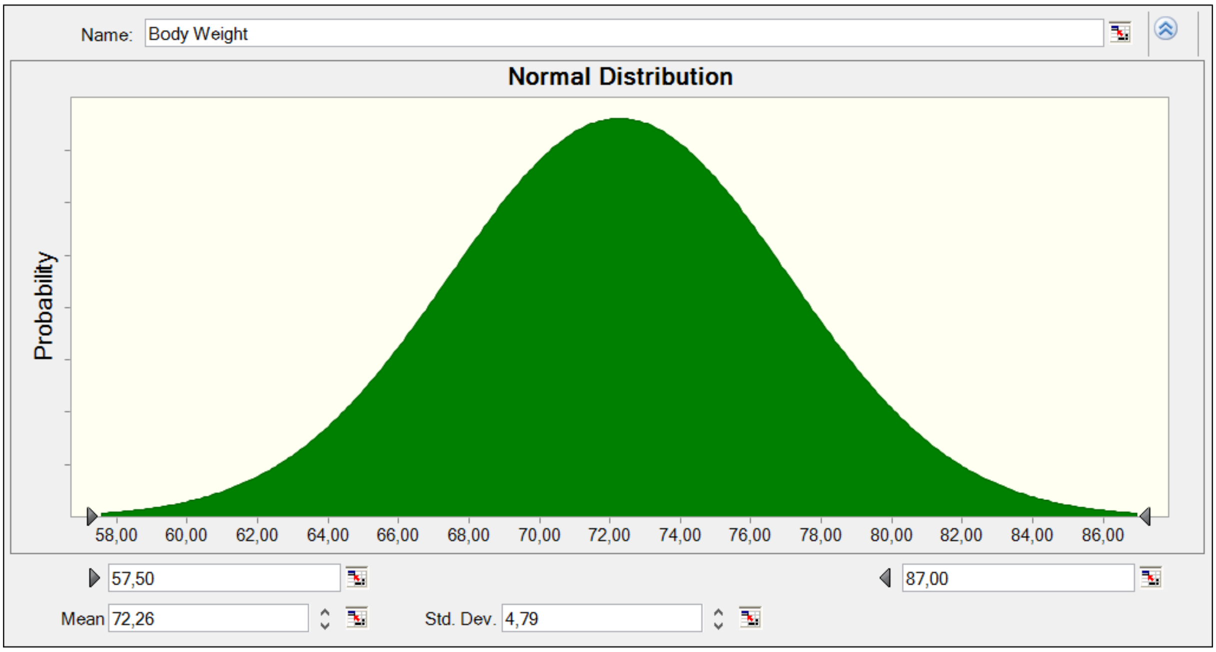
APPENDIX A

INPUT DISTRIBUTIONS

A.1. Input Distributions Used in The Probabilistic Approach of Simav District



Name: Body Weight

Normal Distribution

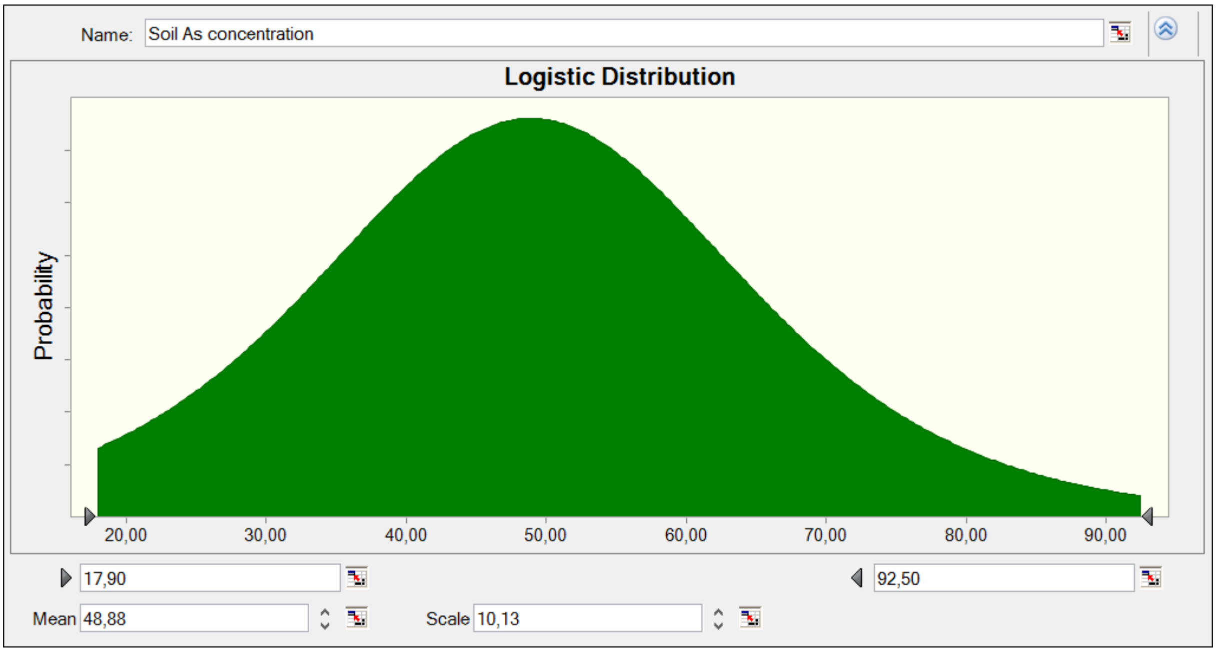
57,50

87,00

Mean 72,26

Std. Dev. 4,79

Fig.A.1. Input distribution of the body weight data



Name: Soil As concentration

Logistic Distribution

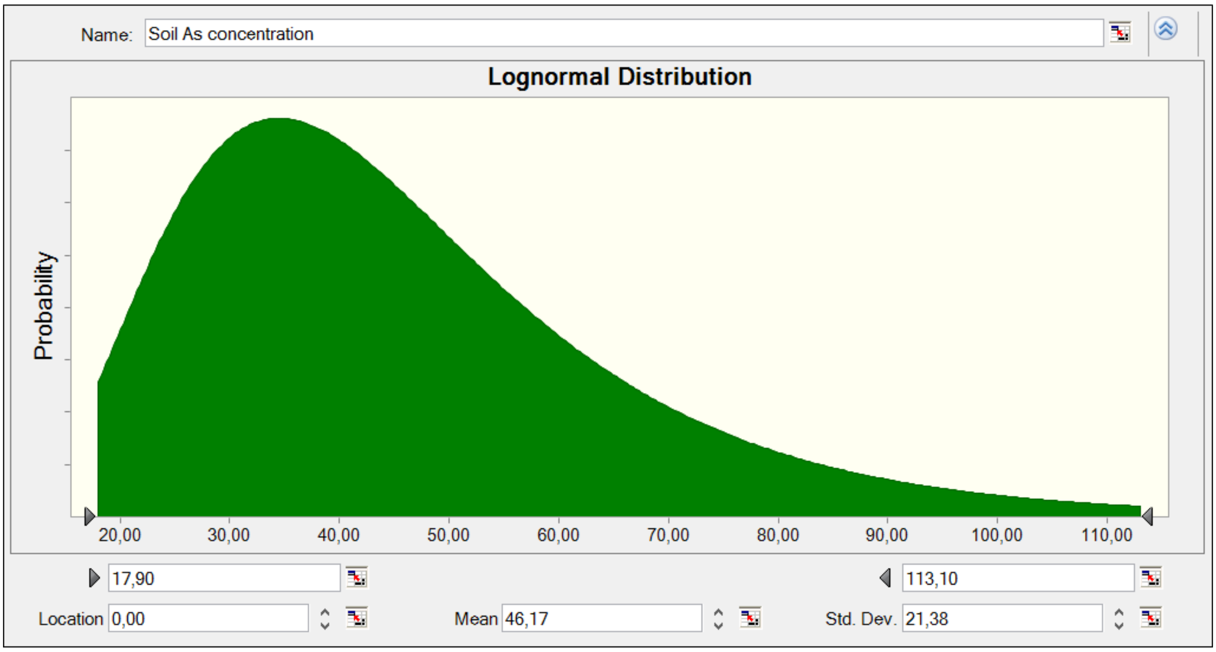
17,90

92,50

Mean 48,88

Scale 10,13

Fig.A.2. Input distribution of the soil arsenic concentrations in one meter depth


Name: Soil As concentration

17,90

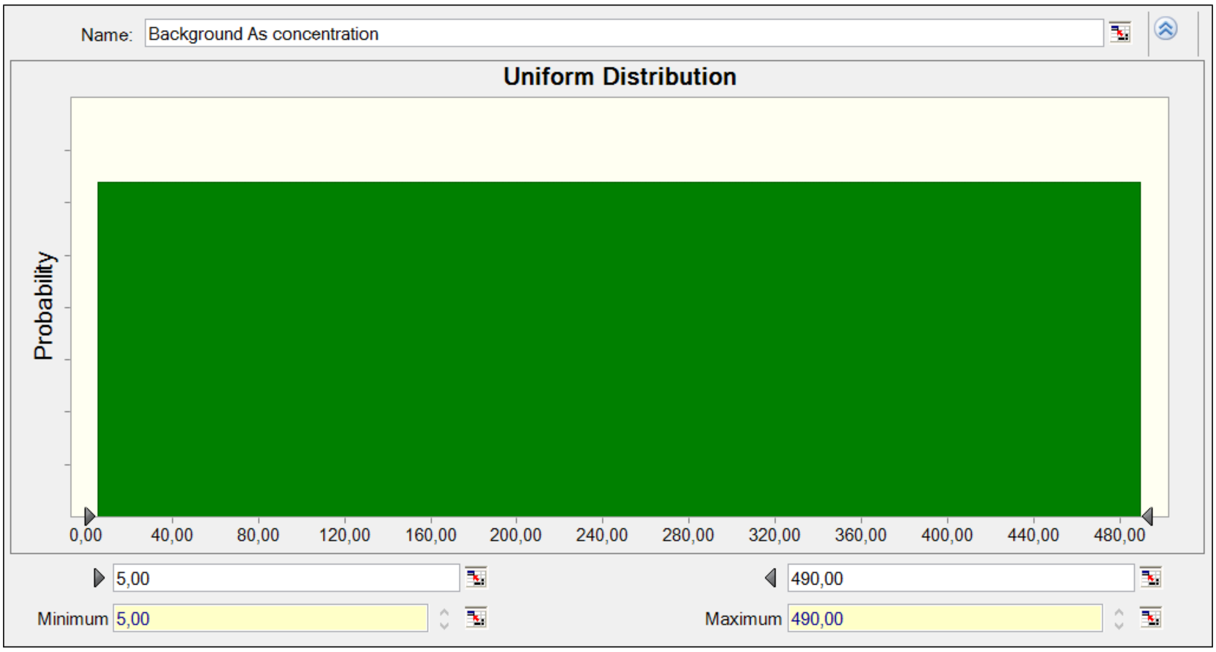
113,10

Location 0,00

Mean 46,17

Std. Dev. 21,38

Fig.A.3. Input distribution of the soil arsenic concentrations one to five meters depth


Name: Background As concentration

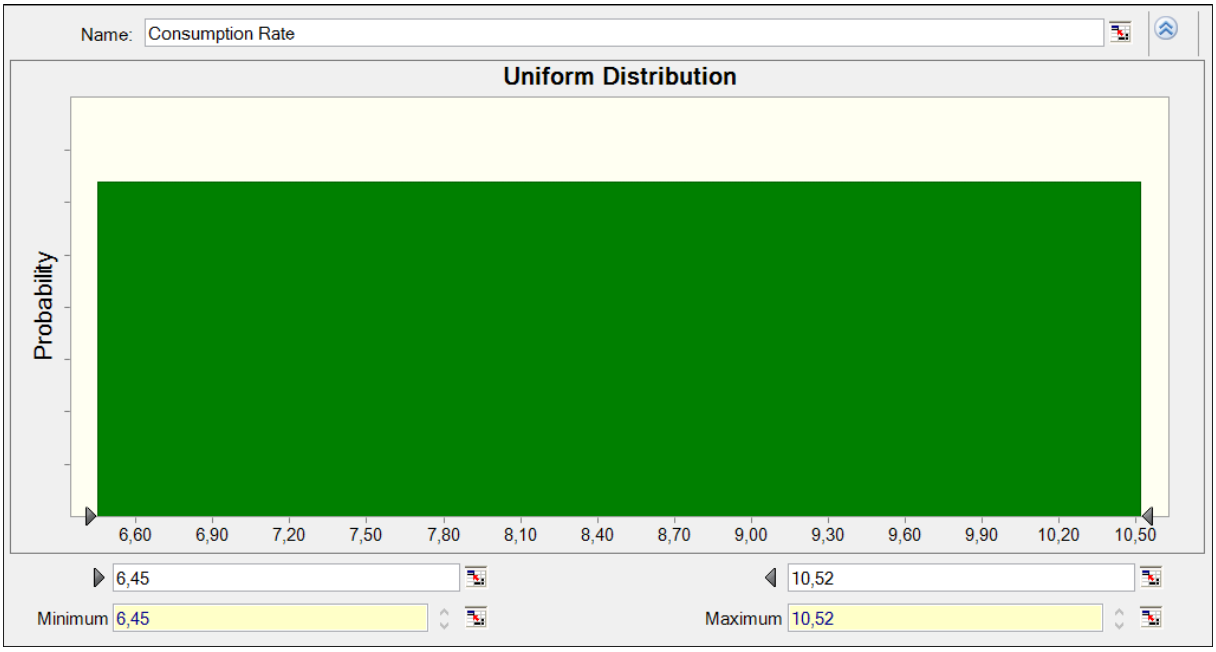
5,00

490,00

Minimum 5,00

Maximum 490,00

Fig.A.4. Input distribution of the background arsenic concentrations of Bean



Name: Consumption Rate

Uniform Distribution

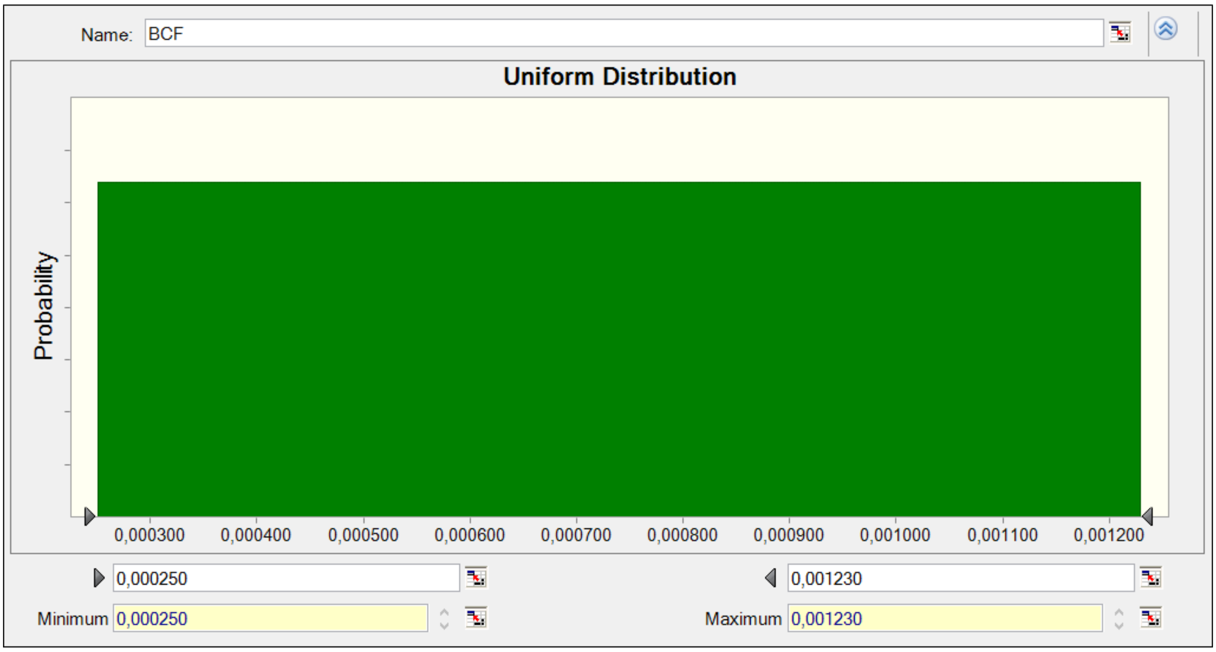
6,45

10,52

Minimum 6,45

Maximum 10,52

Fig.A.5. Input distribution of the consumption rate data of Bean



Name: BCF

Uniform Distribution

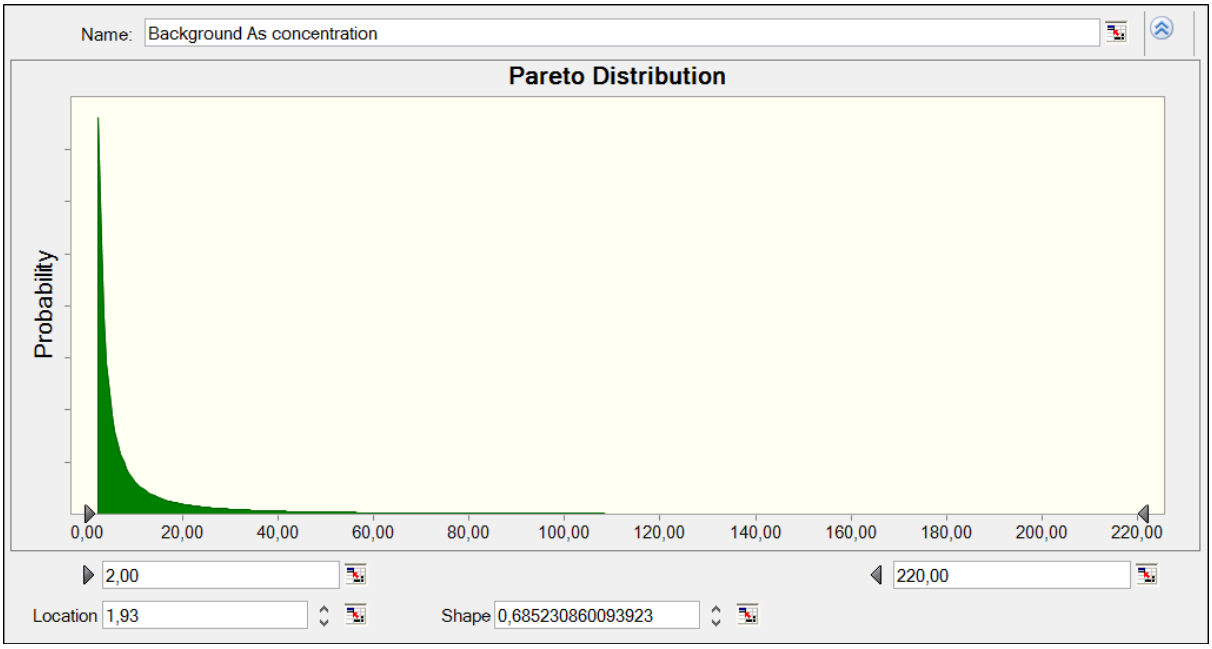
0,000250

0,001230

Minimum 0,000250

Maximum 0,001230

Fig.A.6. Input distribution of the bioconcentration factors of Broccoli



Name: Background As concentration

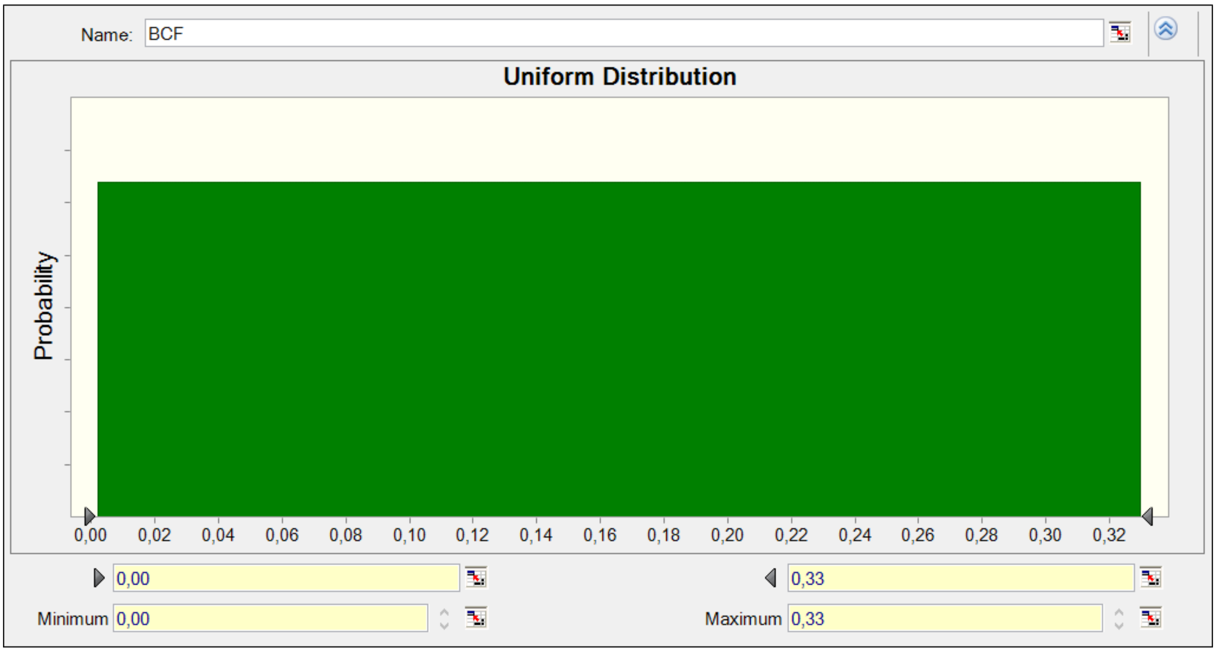
2,00

220,00

Location 1,93

Shape 0,685230860093923

Fig.A.7. Input distribution of the background arsenic concentrations of Broccoli



Name: BCF

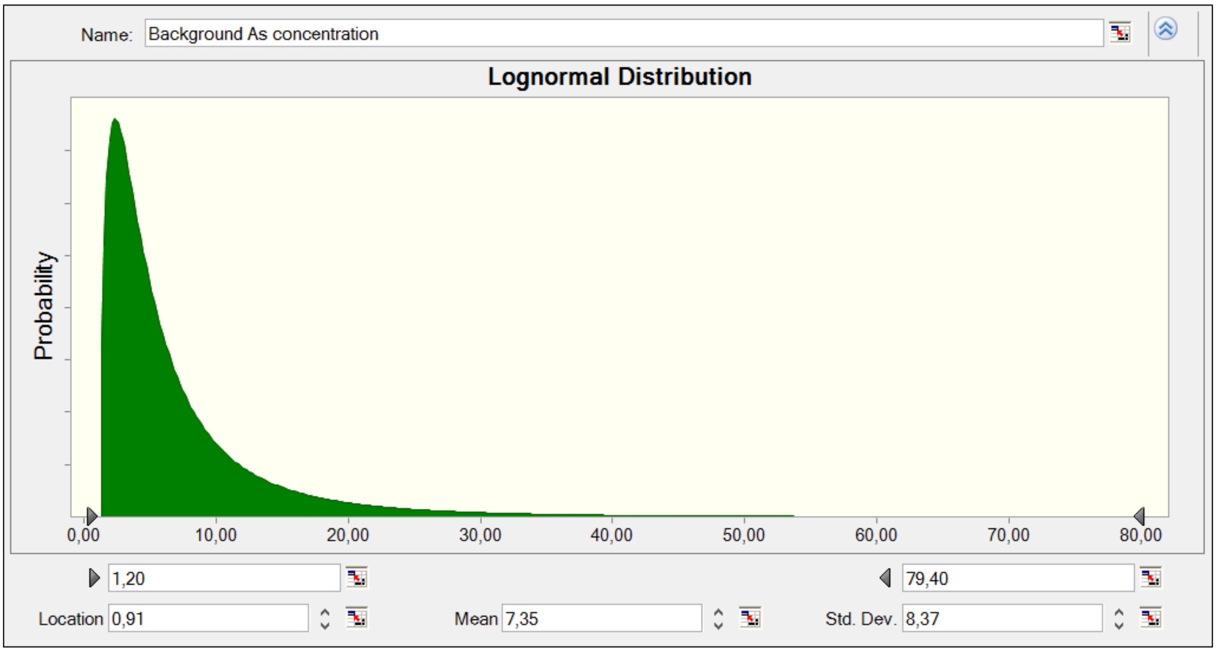
0,00

0,33

Minimum 0,00

Maximum 0,33

Fig.A.8. Input distribution of the bioconcentration factor data of Cabbage


Name: Background As concentration

1,20

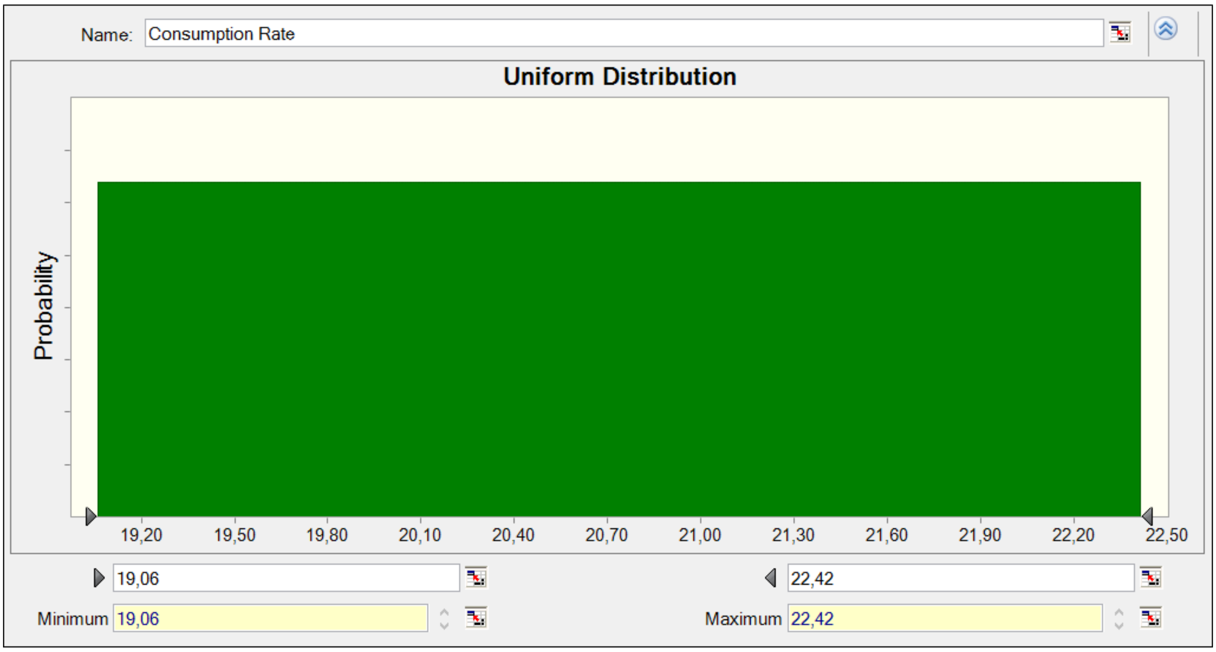
79,40

Location 0,91

Mean 7,35

Std. Dev. 8,37

Fig.A.9. Input distribution of the background arsenic concentrations of Cabbage


Name: Consumption Rate

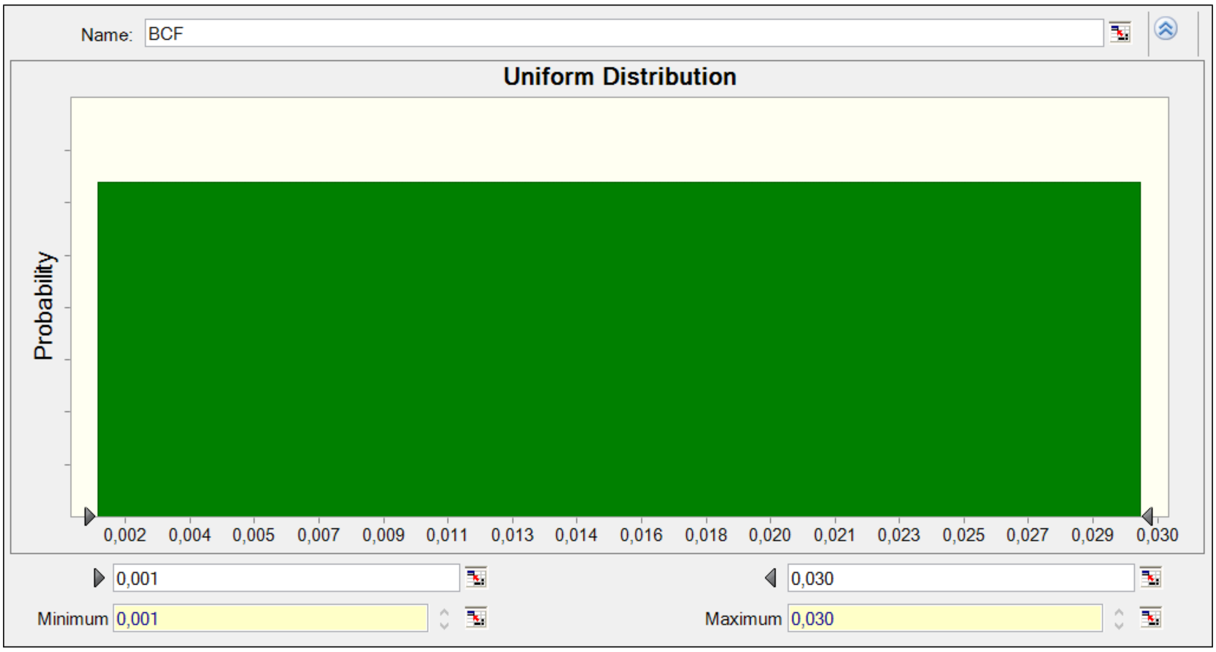
19,06

22,42

Minimum 19,06

Maximum 22,42

Fig.A.10. Input distribution of the consumption rates of Cabbage



Name: BCF

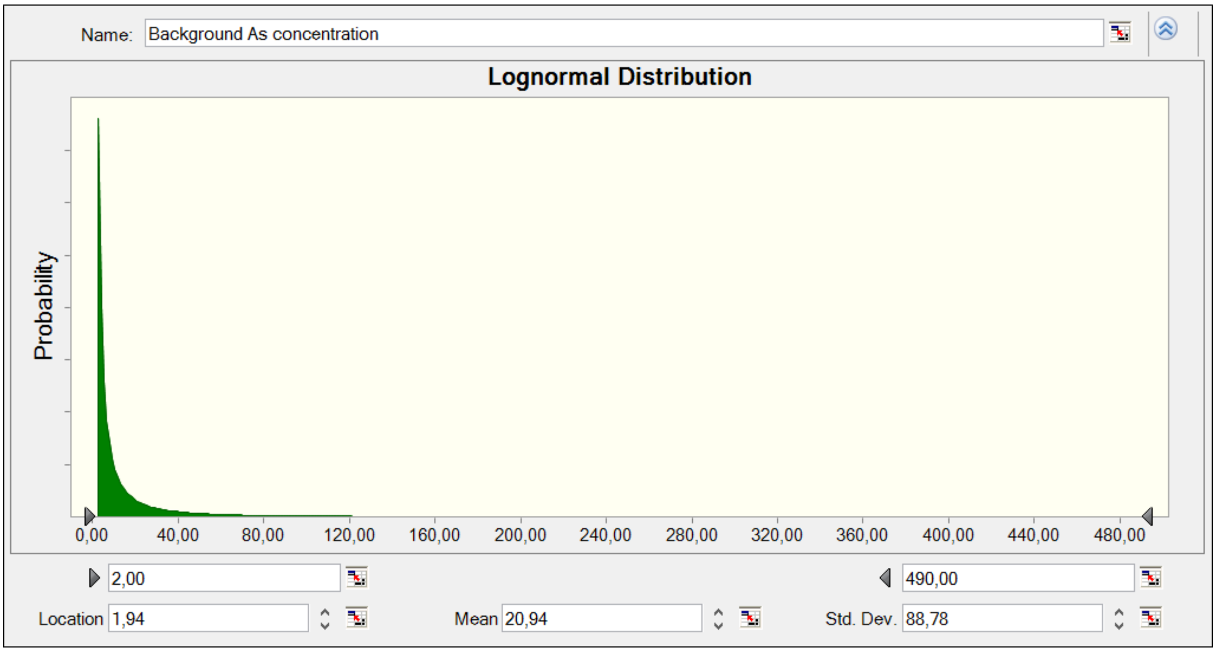
0,001

0,030

Minimum 0,001

Maximum 0,030

Fig.A.11. Input distribution of the bioconcentration factors of Carrot



Name: Background As concentration

2,00

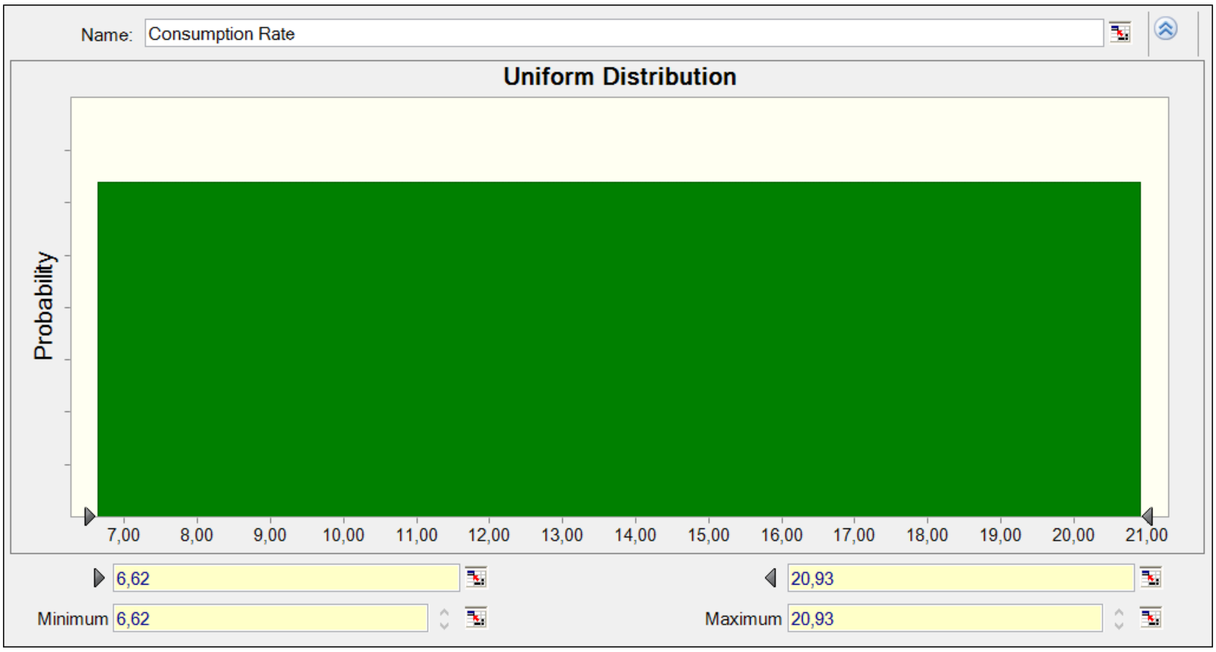
490,00

Location 1,94

Mean 20,94

Std. Dev. 88,78

Fig.A.12. Input distribution of the background arsenic concentrations of Carrot



Name: Consumption Rate

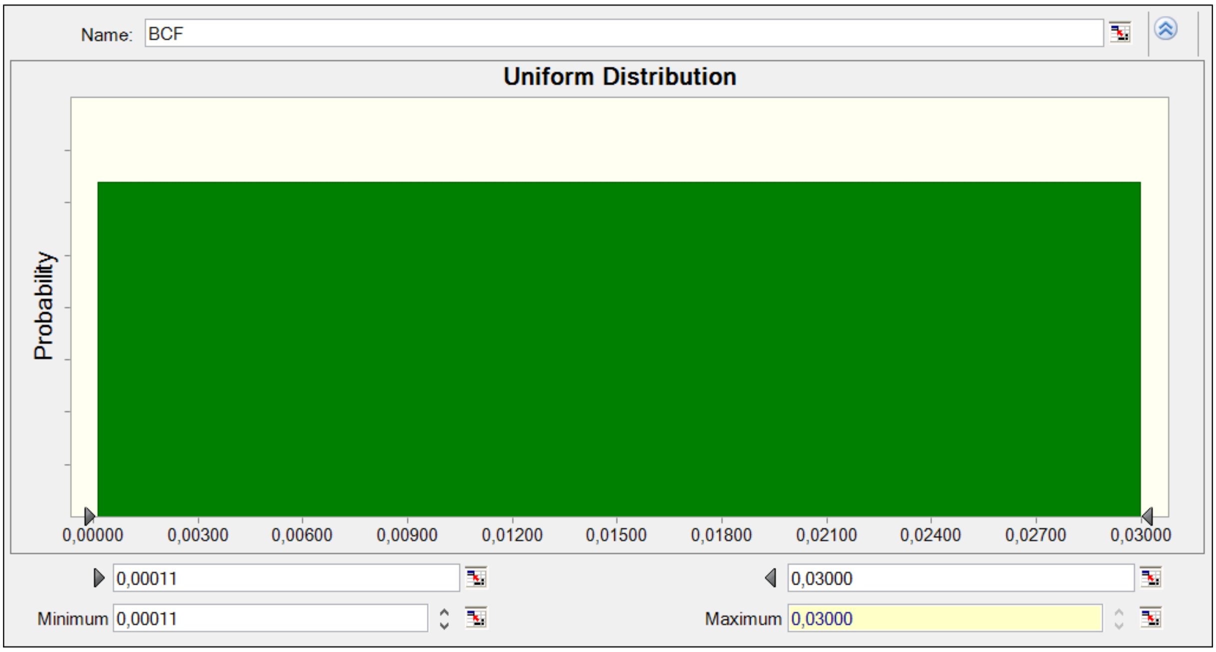
6,62

20,93

Minimum 6,62

Maximum 20,93

Fig.A.13. Input distribution of the consumption rates of Carrot



Name: BCF

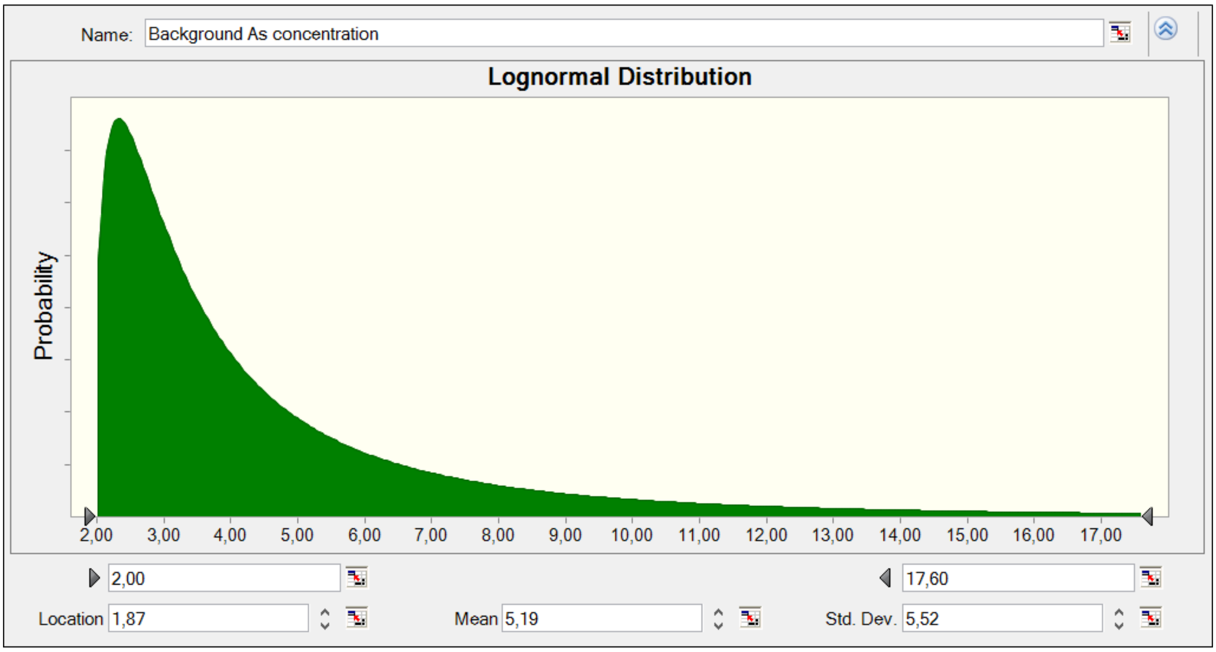
0,00011

0,03000

Minimum 0,00011

Maximum 0,03000

Fig.A.14. Input distribution of the bioconcentration factors of Cauliflower



Name: Background As concentration

2,00

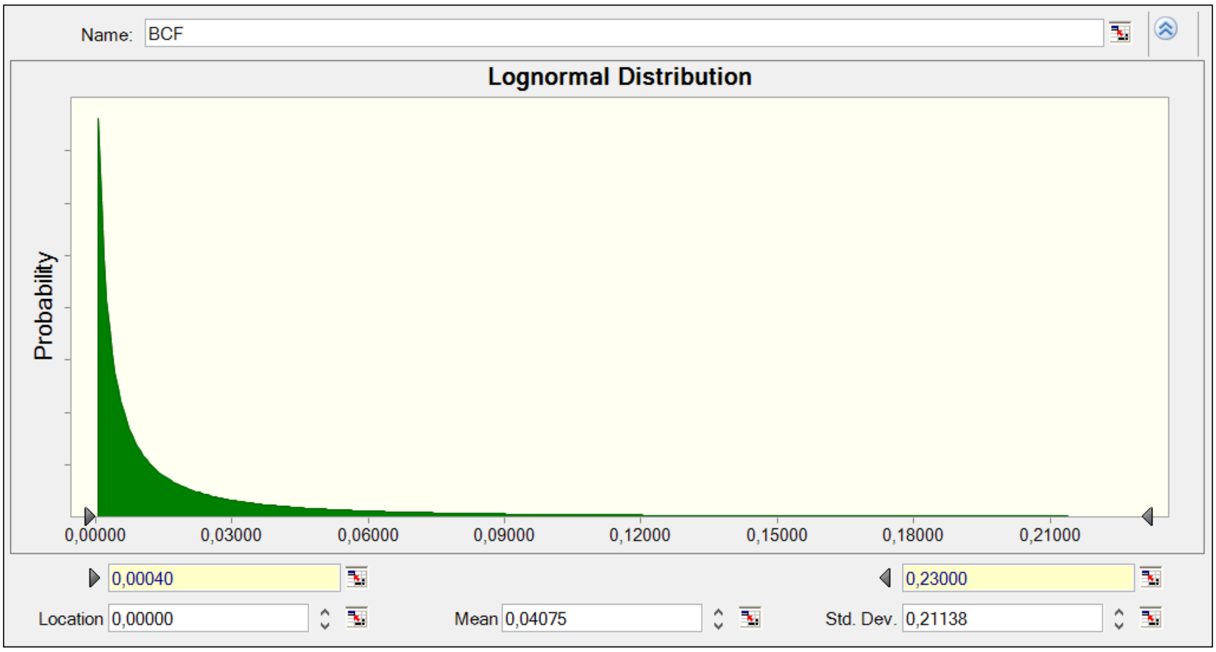
17,60

Location 1,87

Mean 5,19

Std. Dev. 5,52

Fig.A.15. Input distribution of the background arsenic concentrations of Cauliflower



Name: BCF

0,00040

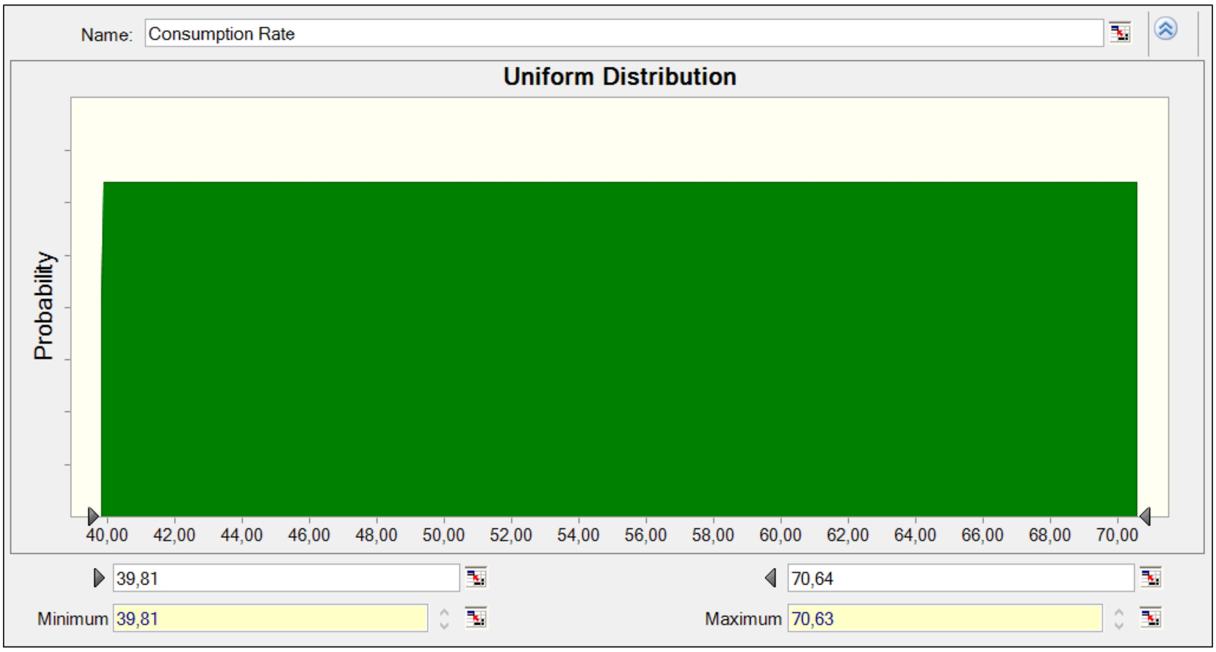
0,23000

Location 0,00000

Mean 0,04075

Std. Dev. 0,21138

Fig.A.16. Input distribution of the bioconcentration factors of Corn


Name: Consumption Rate

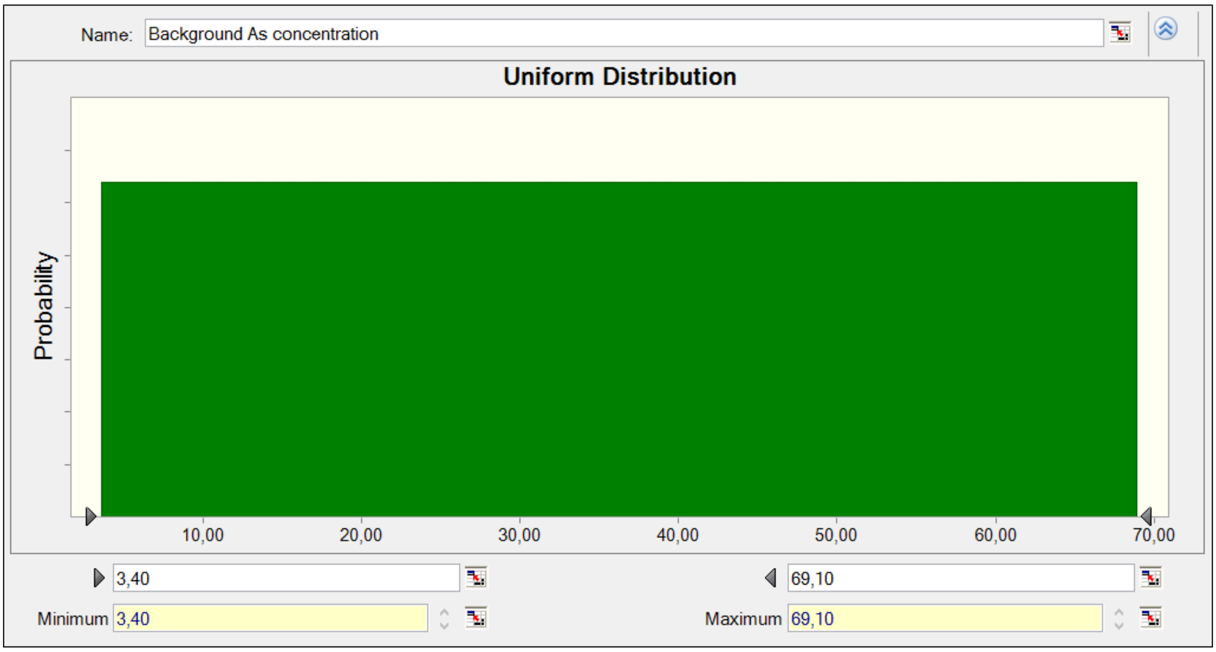
39,81

70,64

Minimum 39,81

Maximum 70,63

Fig.A.17. Input distribution of the consumption rate data of Corn


Name: Background As concentration

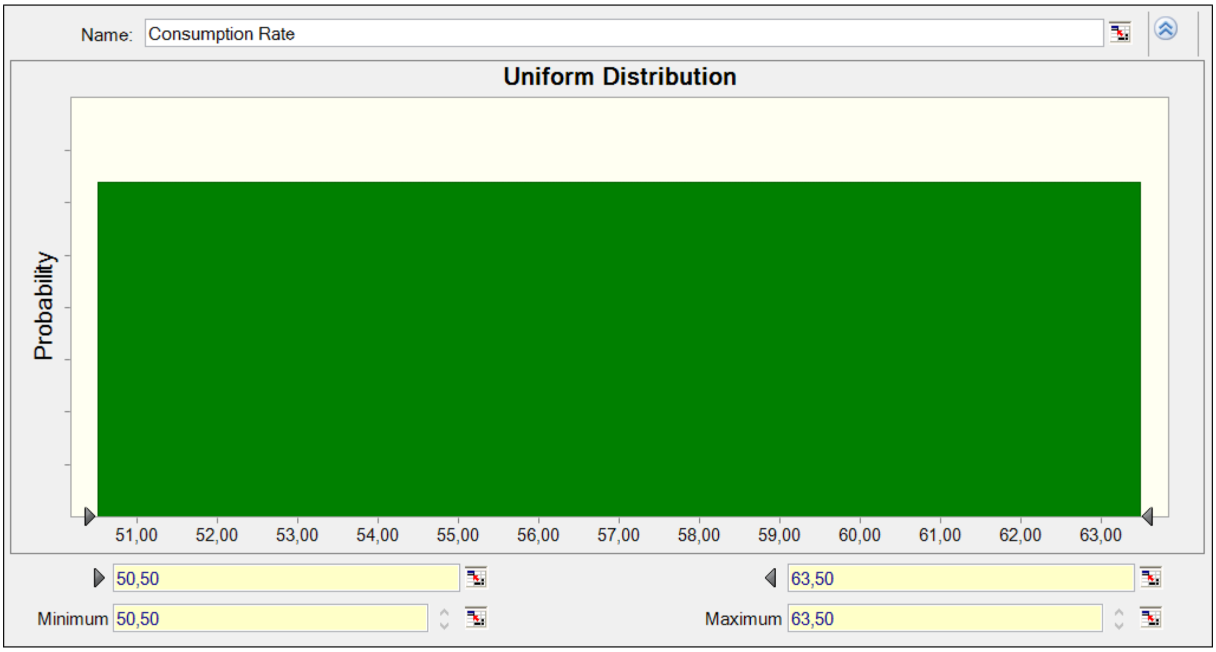
3,40

69,10

Minimum 3,40

Maximum 69,10

Fig.A.18. Input distribution of the background arsenic concentrations of Cucumber

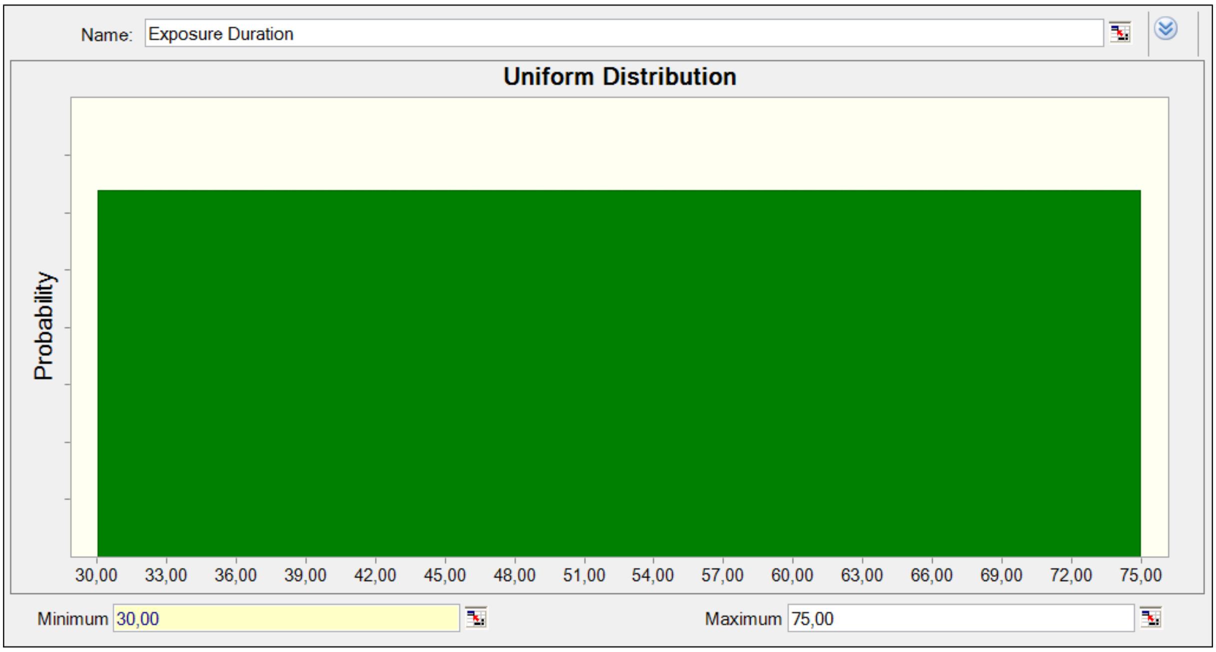


Name: Consumption Rate

50,50 63,50

Minimum 50,50 Maximum 63,50

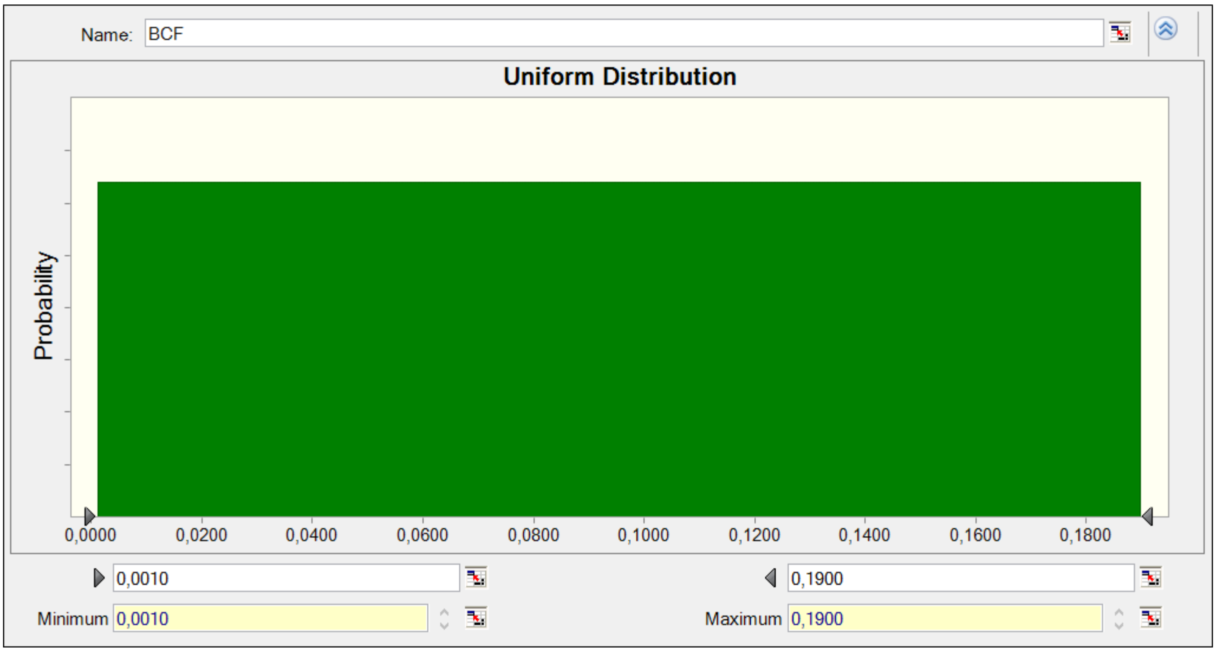
Fig.A.19. Input distribution of the consumption rate data of Cucumber



Name: Exposure Duration

Minimum 30,00 Maximum 75,00

Fig.A.20. Input distribution of the exposure duration for carcinogenic risk asssessment


Name: BCF

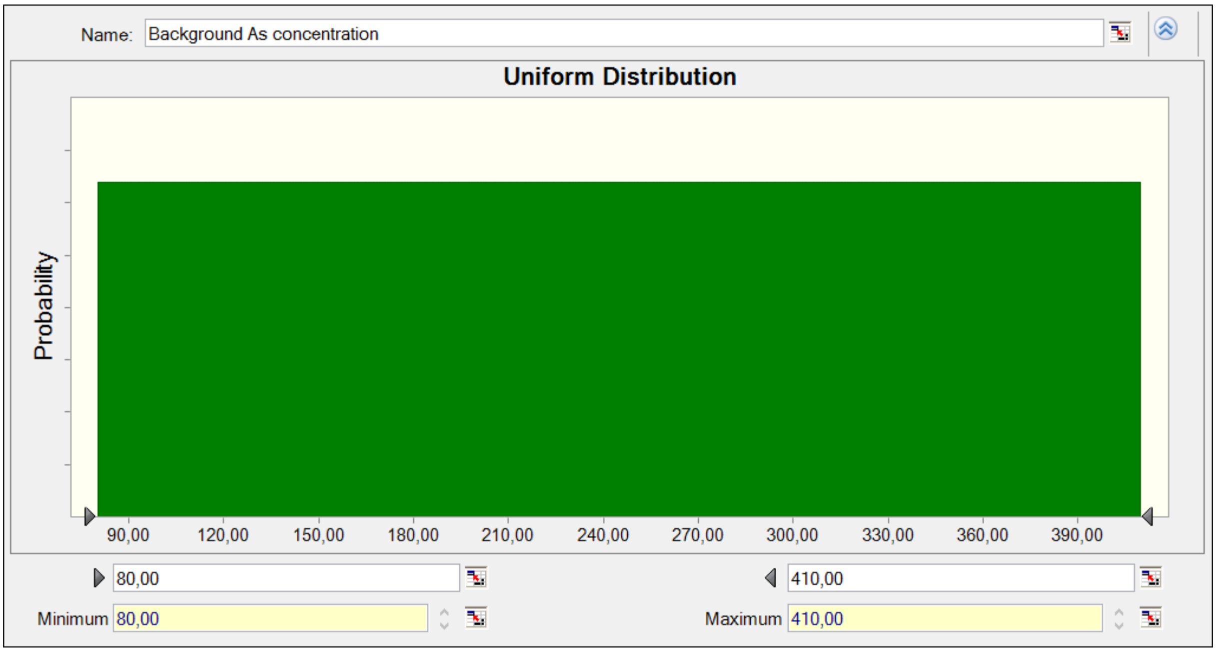
0,0010

0,1900

Minimum 0,0010

Maximum 0,1900

Fig.A.21. Input distribution of the bioconcentration factors of Eggplant


Name: Background As concentration

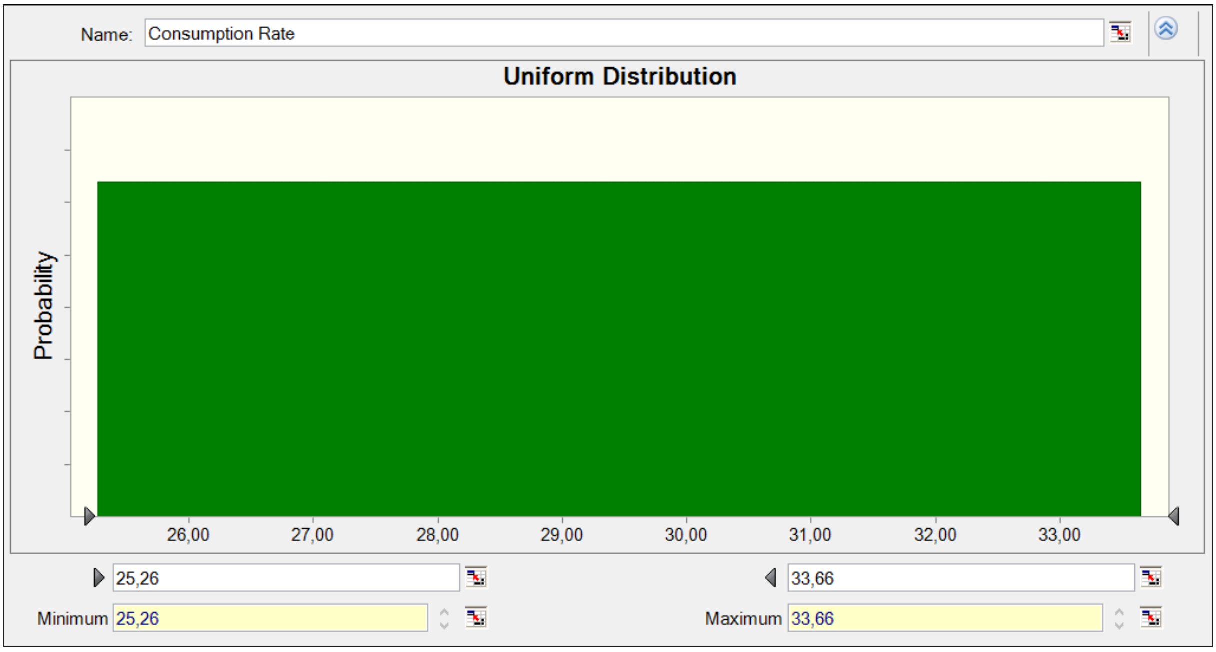
80,00

410,00

Minimum 80,00

Maximum 410,00

Fig.A.22. Input distribution of the background arsenic concentrations of Eggplant



Name: Consumption Rate

Uniform Distribution

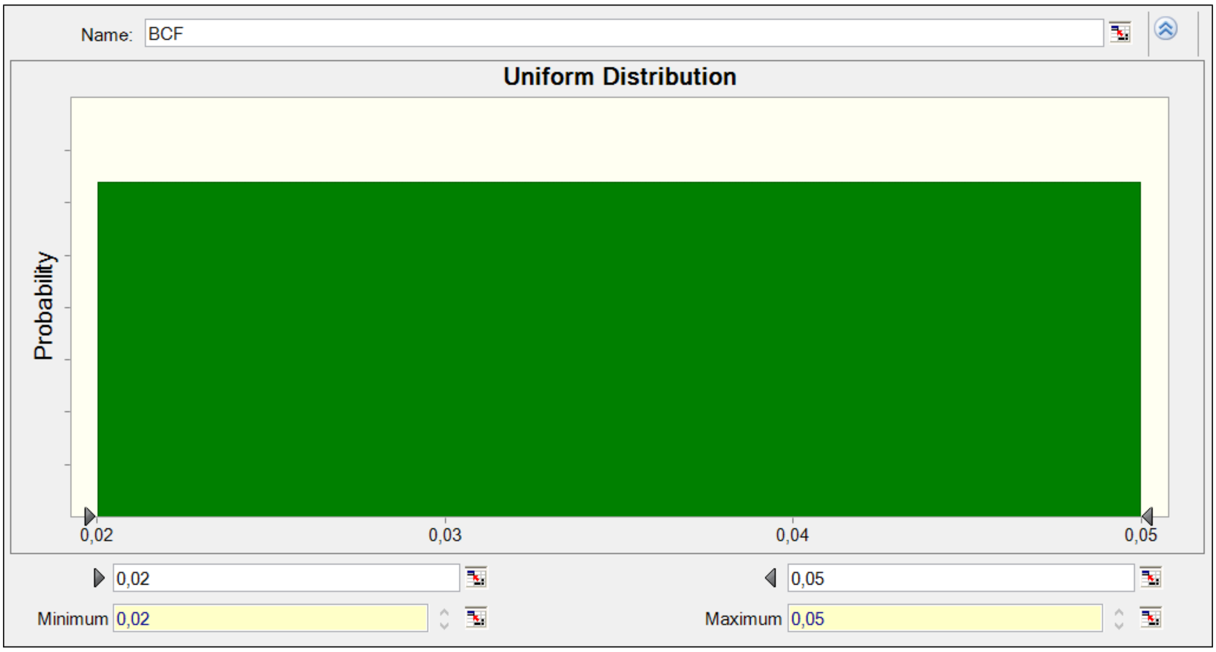
25,26

33,66

Minimum 25,26

Maximum 33,66

Fig.A.23. Input distribution of the consumption rate data of Eggplant



Name: BCF

Uniform Distribution

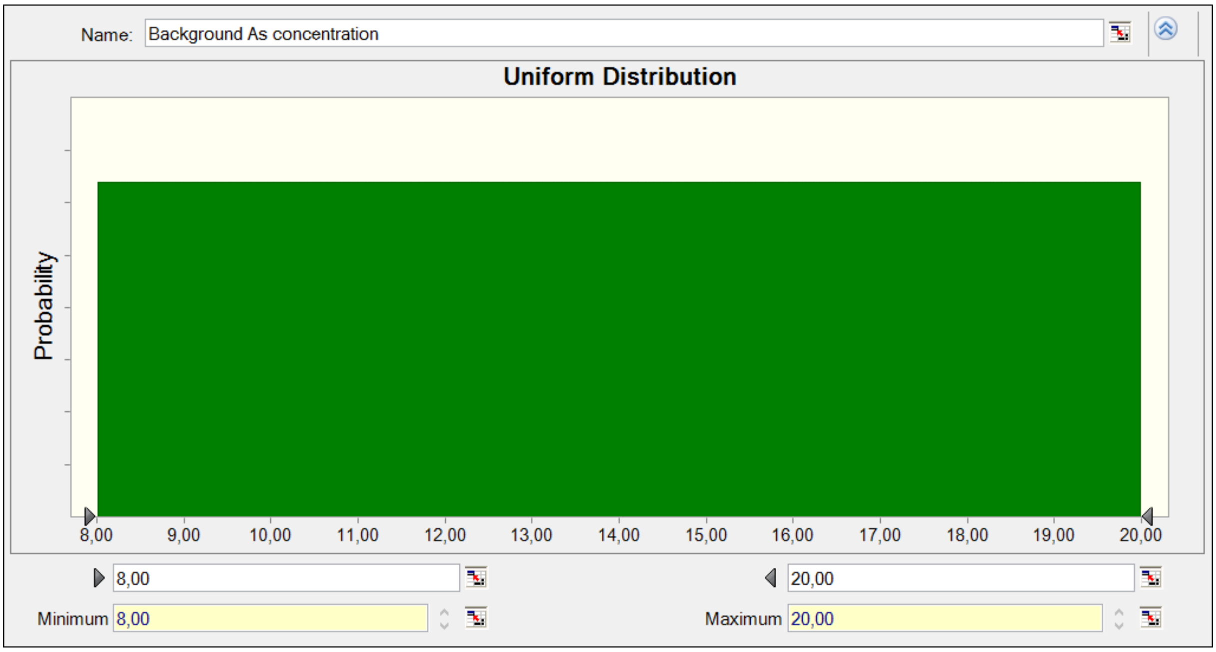
0,02

0,05

Minimum 0,02

Maximum 0,05

Fig.A.24. Input distribution of the bioconcentration factors of Garlic

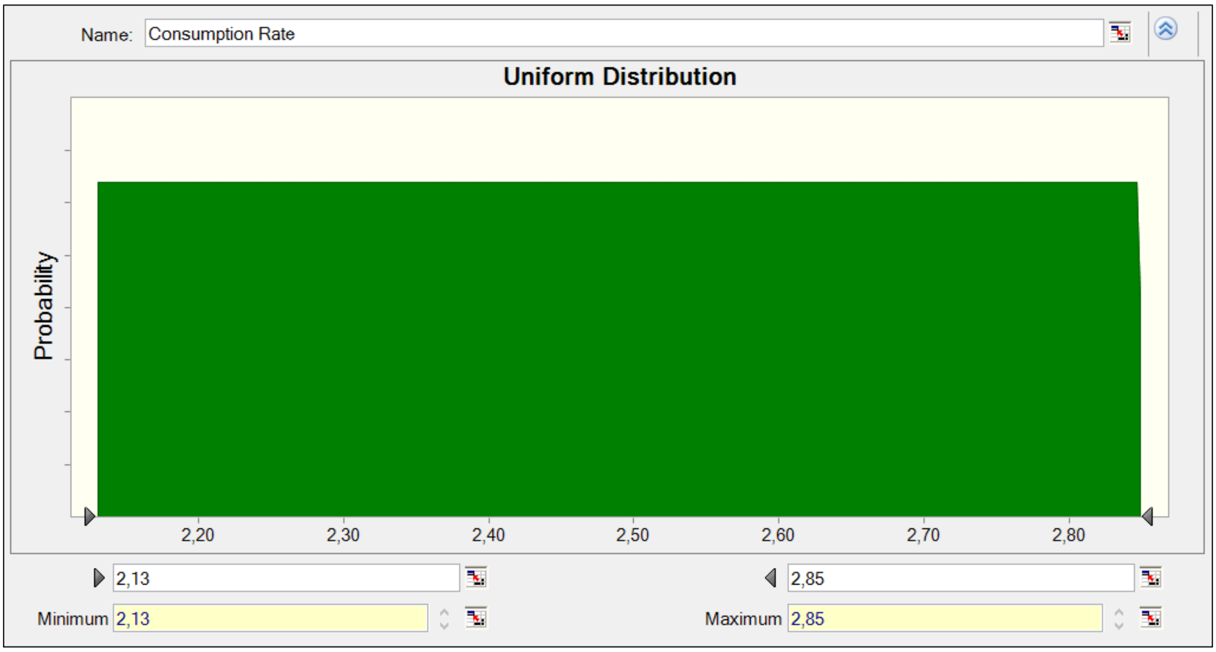

Name: Background As concentration

Uniform Distribution

8,00 20,00

Minimum 8,00 Maximum 20,00

Fig.A.25. Input distribution of the background As concentrations of Garlic

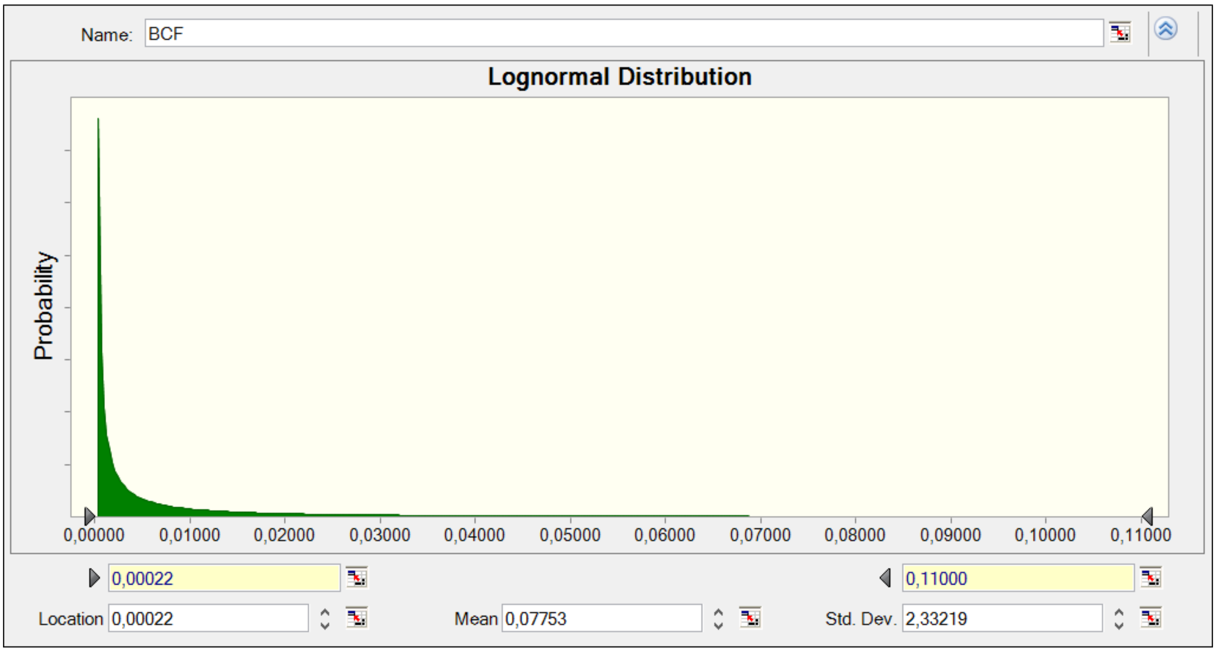

Name: Consumption Rate

Uniform Distribution

2,13 2,85

Minimum 2,13 Maximum 2,85

Fig.A.26. Input distribution of the consumption rates of Garlic

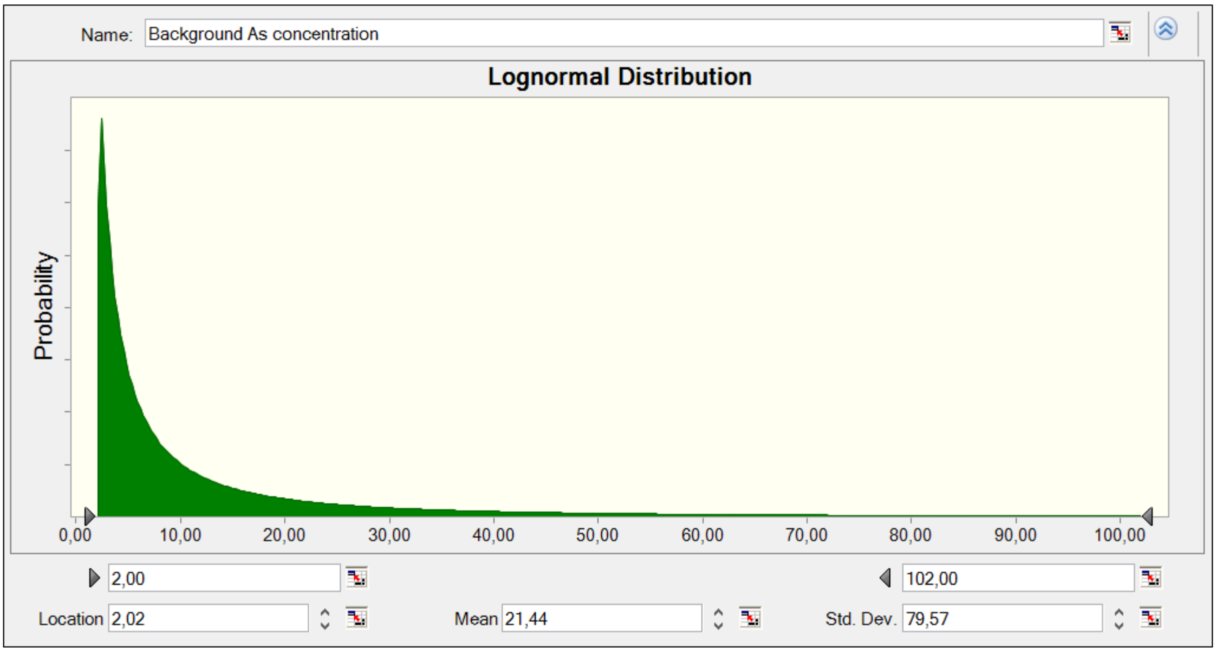


Name: BCF

0,00022 0,11000

Location 0,00022 Mean 0,07753 Std. Dev. 2,33219

Fig.A.27. Input distribution of the bioconcentration factors of Lettuce

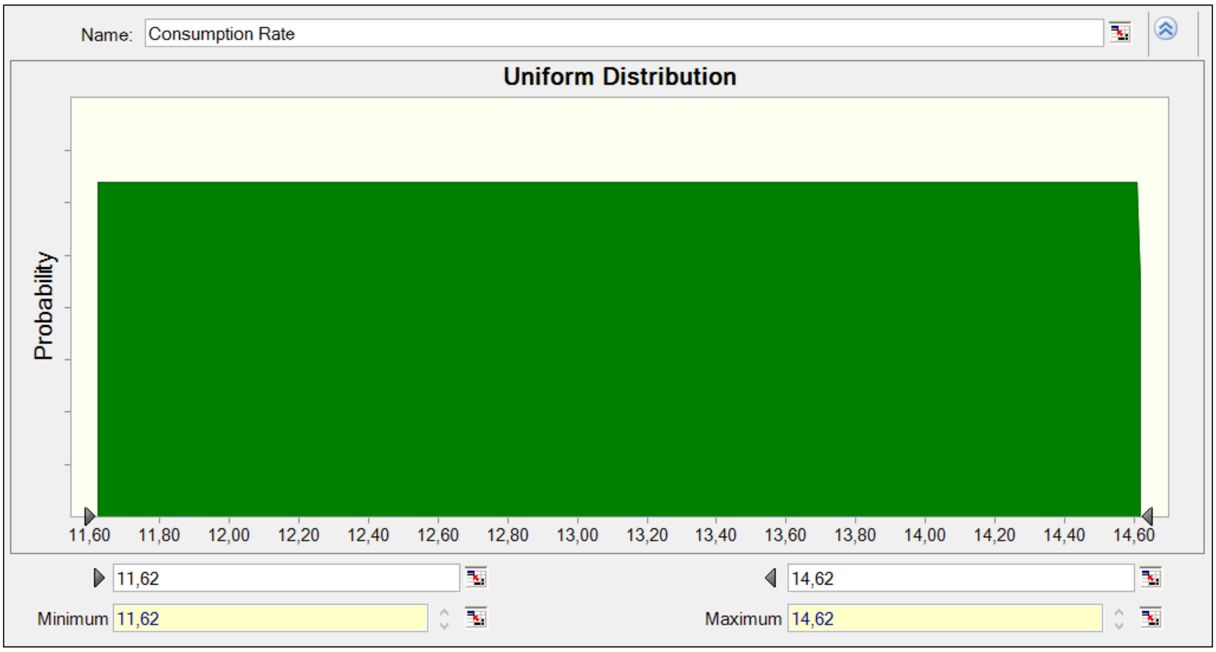


Name: Background As concentration

2,00 102,00

Location 2,02 Mean 21,44 Std. Dev. 79,57

Fig.A.28. Input distribution of the background As concentrations of Lettuce



Name: Consumption Rate

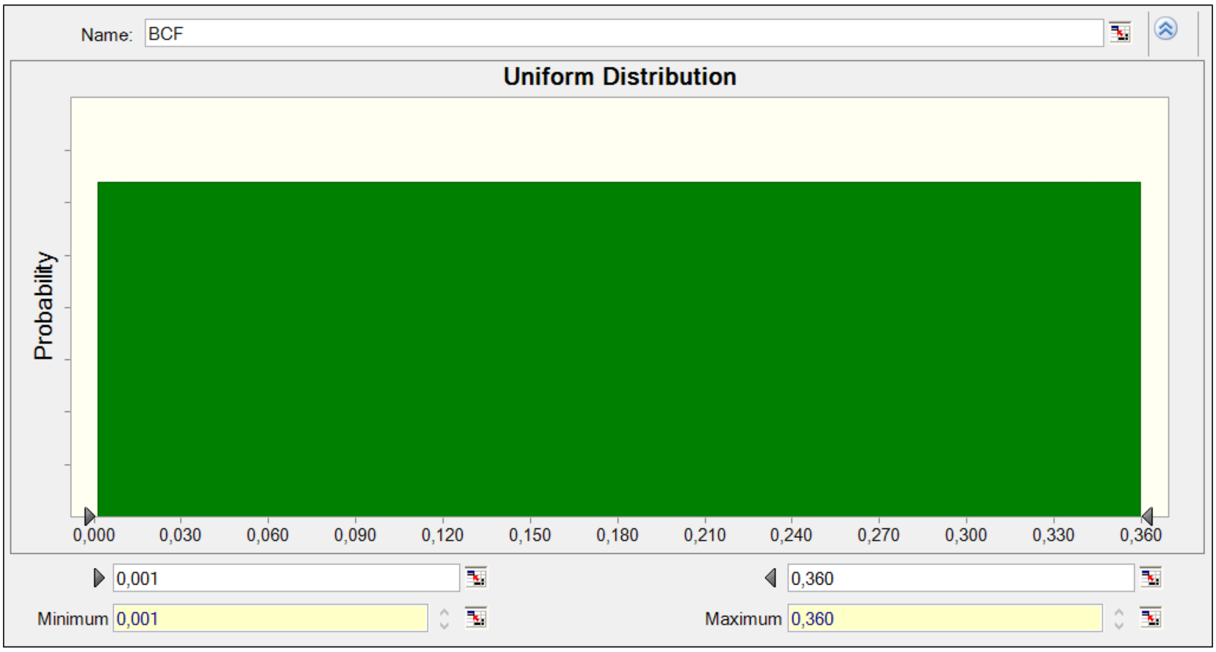
11,62

14,62

Minimum 11,62

Maximum 14,62

Fig.A.29. Input distribution of the consumption rates of Lettuce



Name: BCF

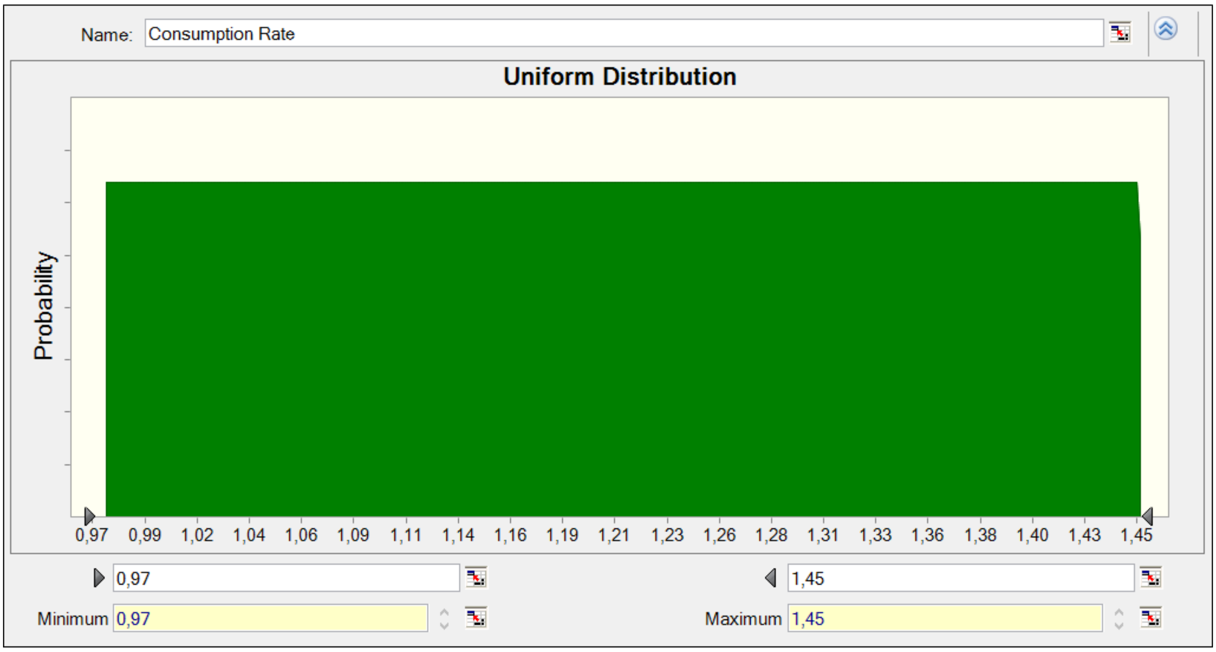
0,001

0,360

Minimum 0,001

Maximum 0,360

Fig.A.30. Input distribution of the bioconcentration factors of Okra



Name: Consumption Rate

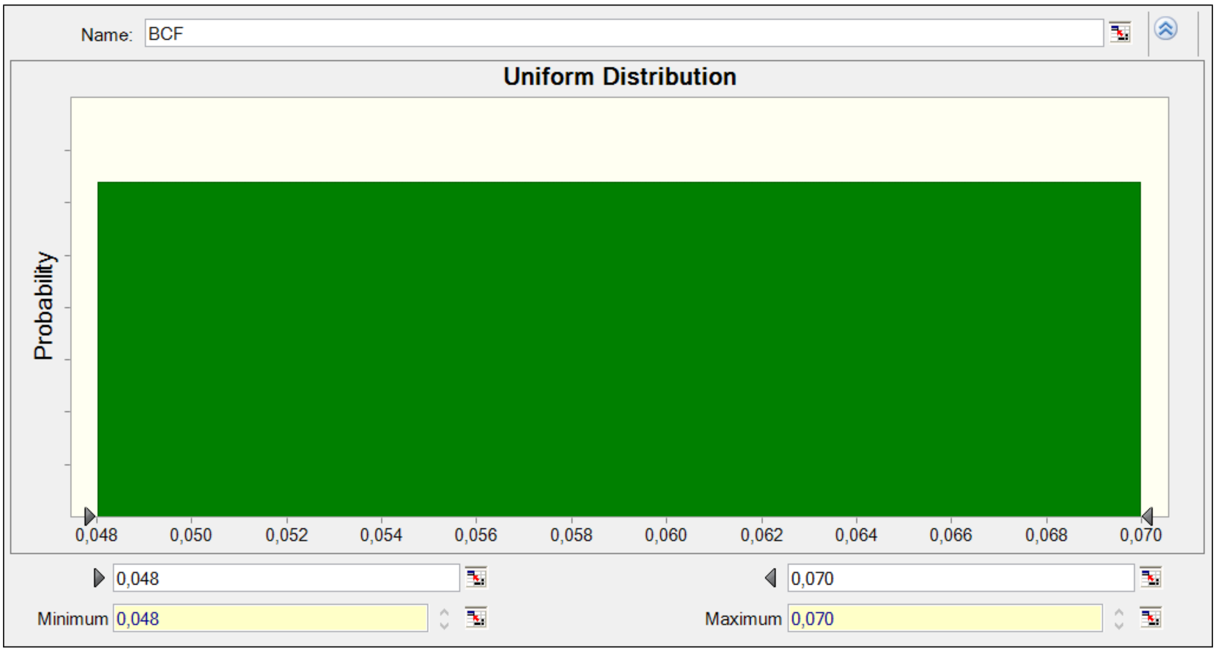
0,97

1,45

Minimum 0,97

Maximum 1,45

Fig.A.31. Input distribution of the consumption rates of Okra



Name: BCF

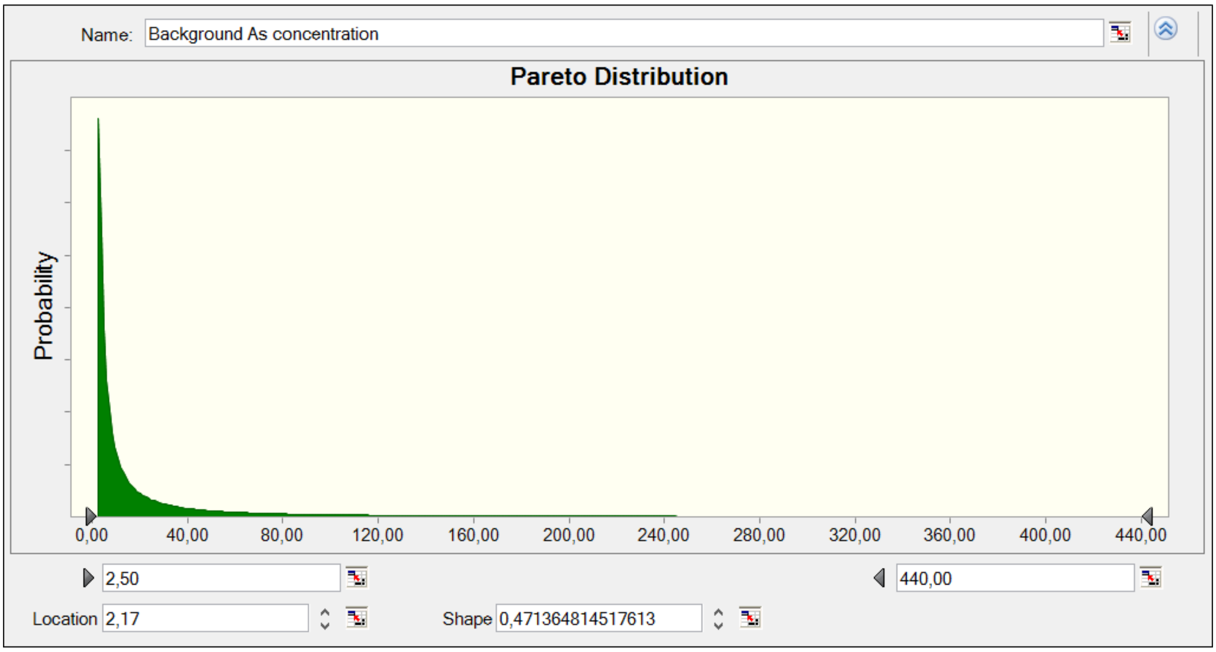
0,048

0,070

Minimum 0,048

Maximum 0,070

Fig.A.32. Input distribution of the bioconcentration factors of Onion



Name: Background As concentration

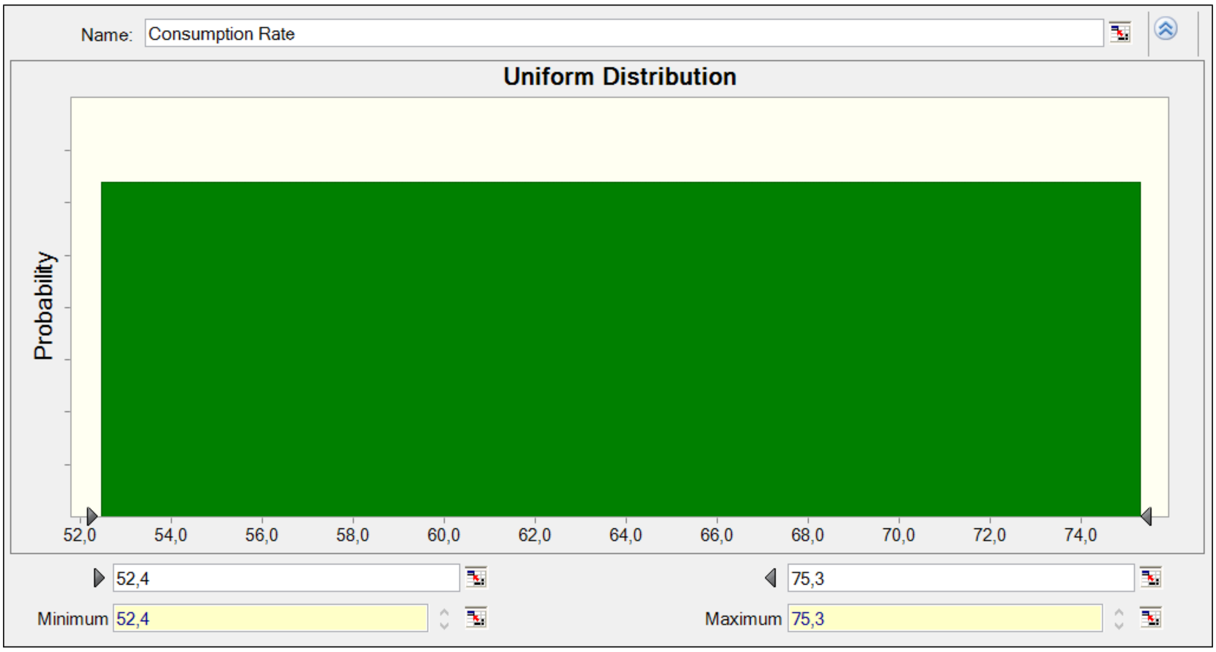
2,50

440,00

Location 2,17

Shape 0,471364814517613

Fig.A.33. Input distribution of the background As concentrations of Onion



Name: Consumption Rate

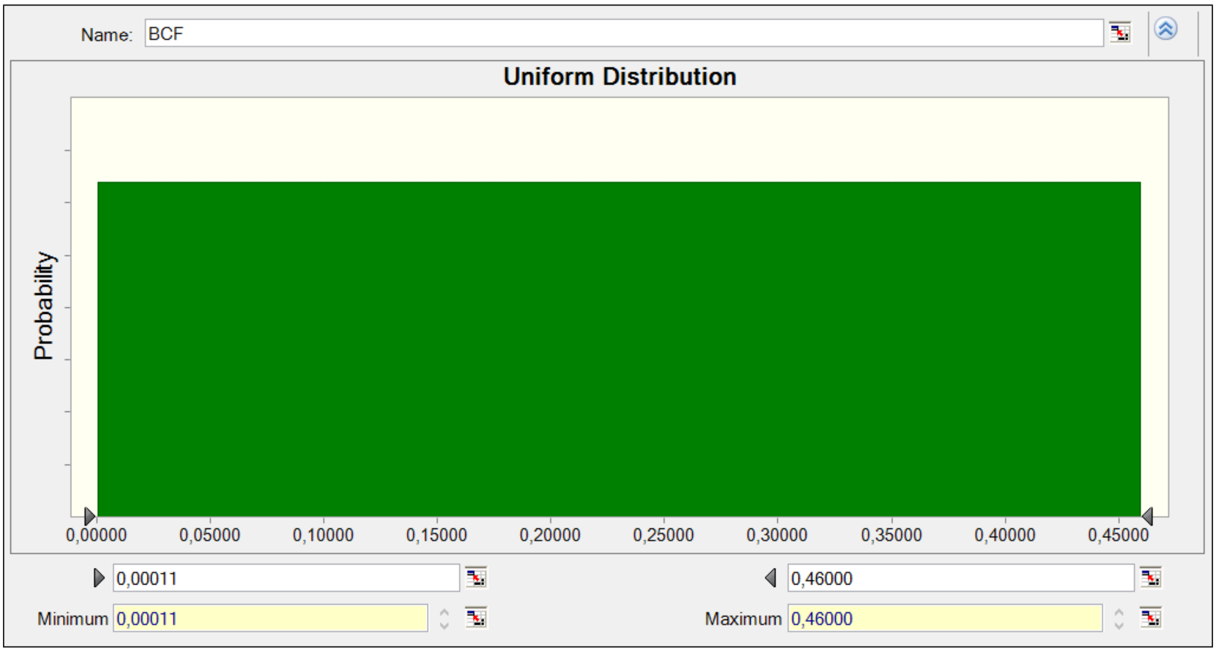
52,4

75,3

Minimum 52,4

Maximum 75,3

Fig.A.34. Input distribution of the consumption rates of Onion


Name: BCF

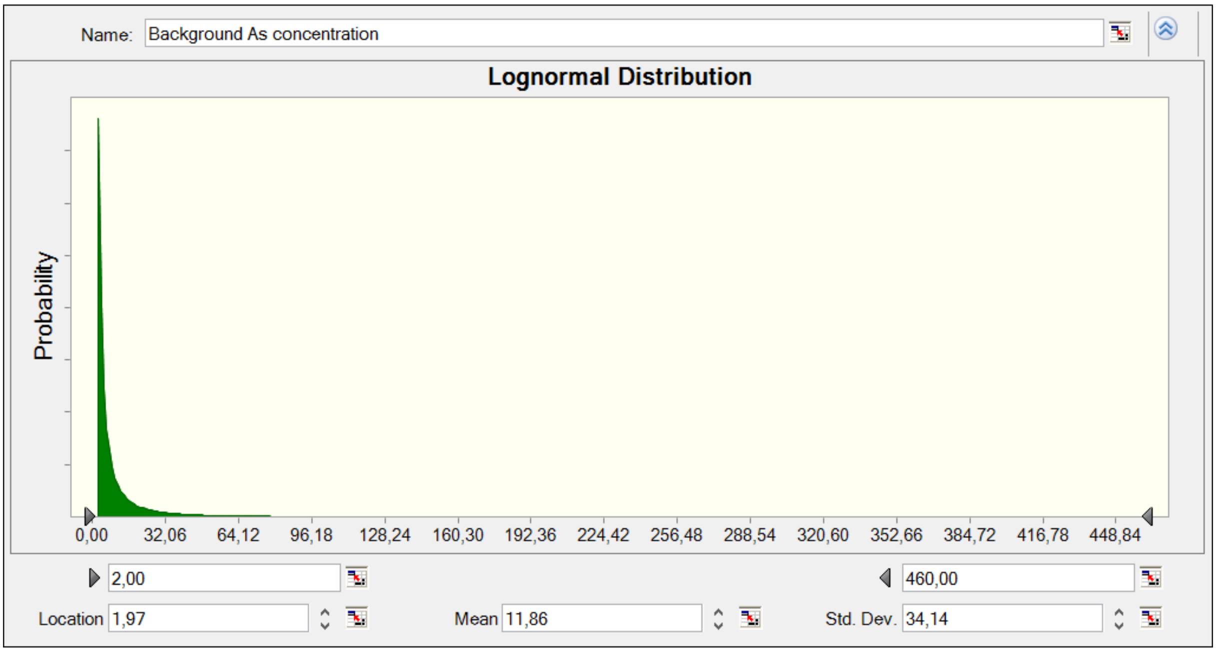
0,00011

0,46000

Minimum 0,00011

Maximum 0,46000

Fig.A.35. Input distribution of the bioconcentration factors of Potato


Name: Background As concentration

2,00

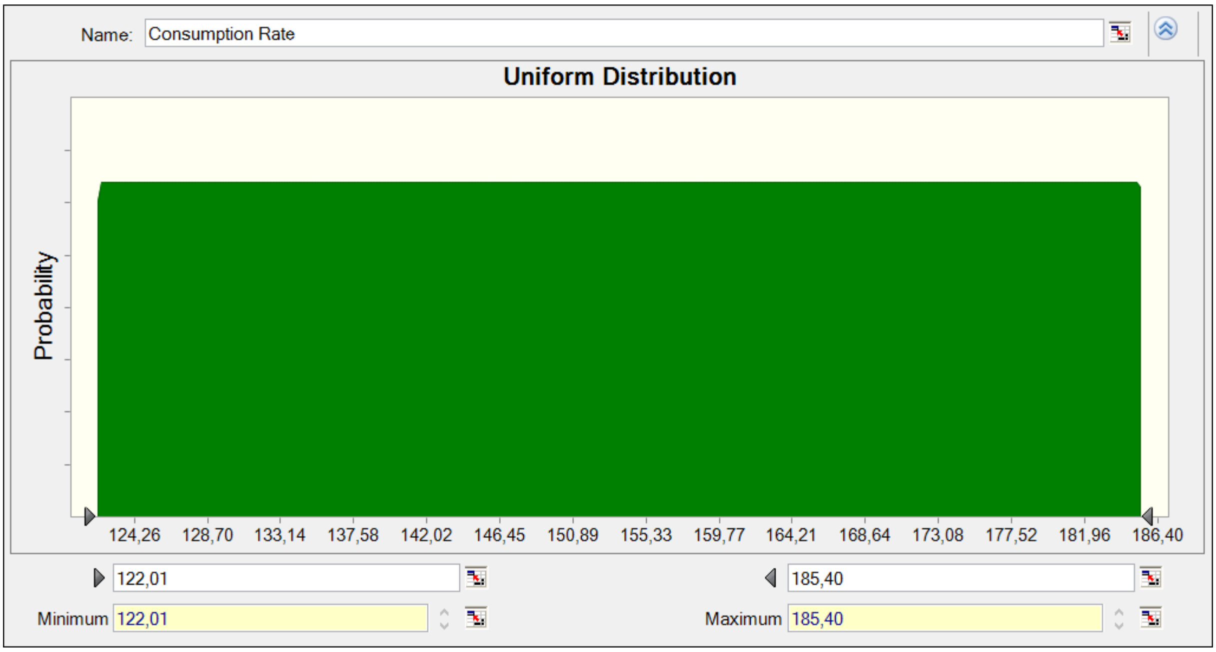
460,00

Location 1,97

Mean 11,86

Std. Dev. 34,14

Fig.A.36 Input distribution of the background As concentrations of Potato


Name: Consumption Rate

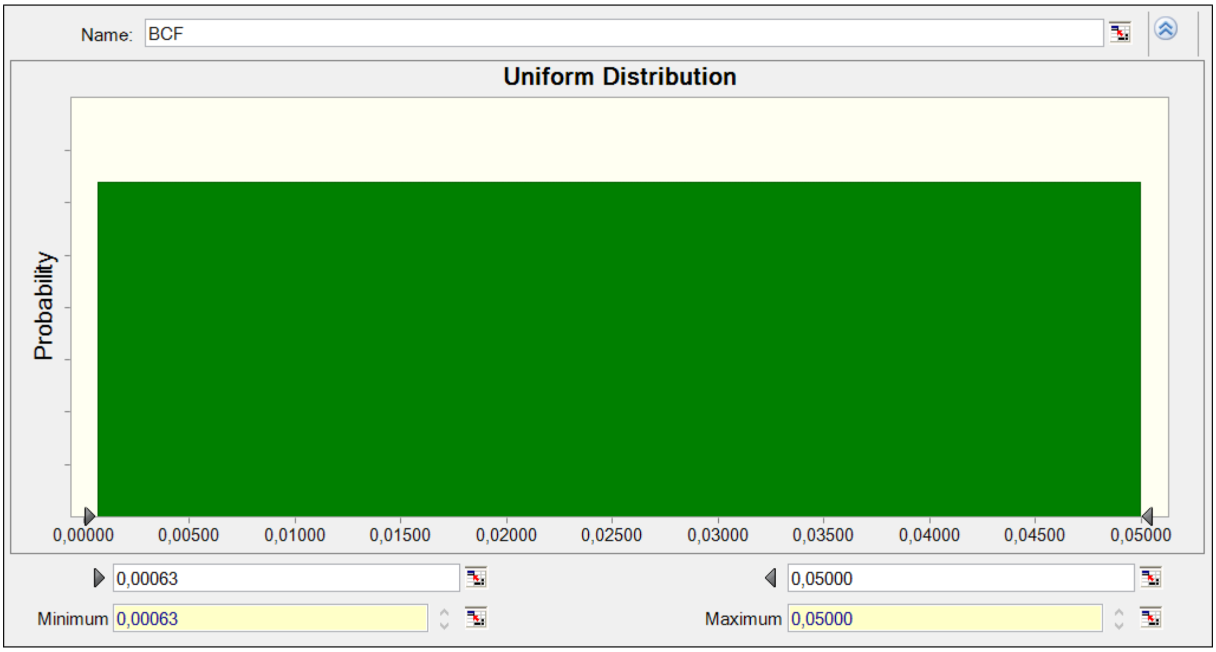
122,01

185,40

Minimum 122,01

Maximum 185,40

Fig.A.37. Input distribution of the consumption rate data of Potato


Name: BCF

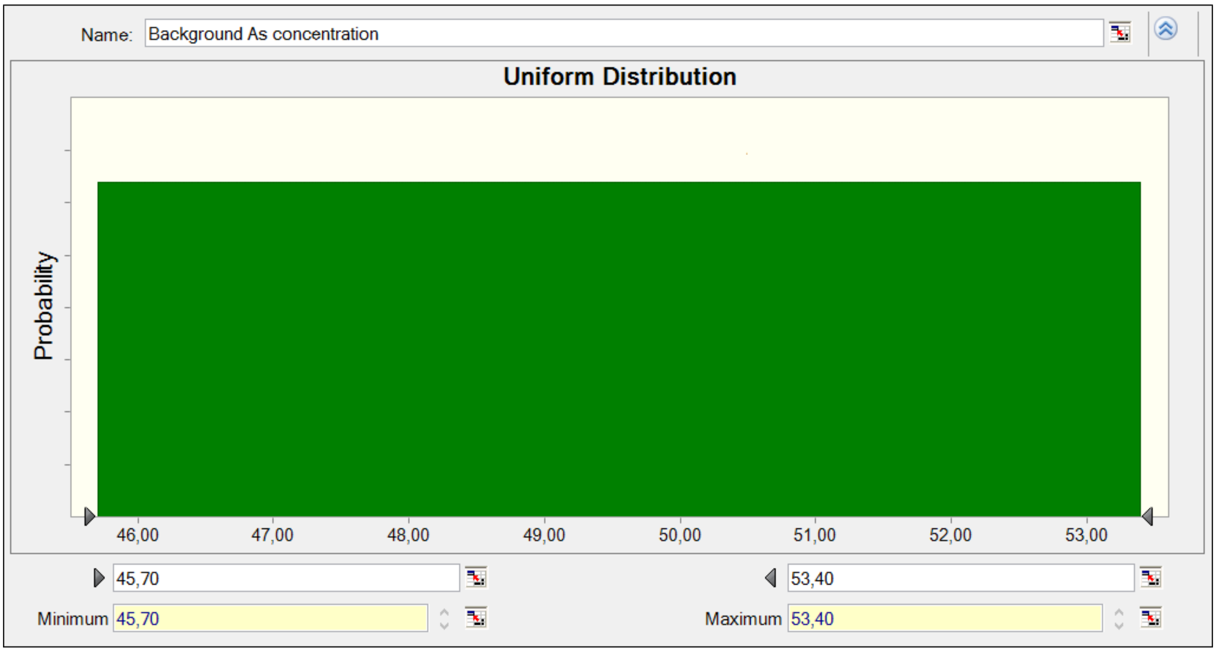
0,00063

0,05000

Minimum 0,00063

Maximum 0,05000

Fig.A.38. Input distribution of the bioconcentration factors of Radish



Name: Background As concentration

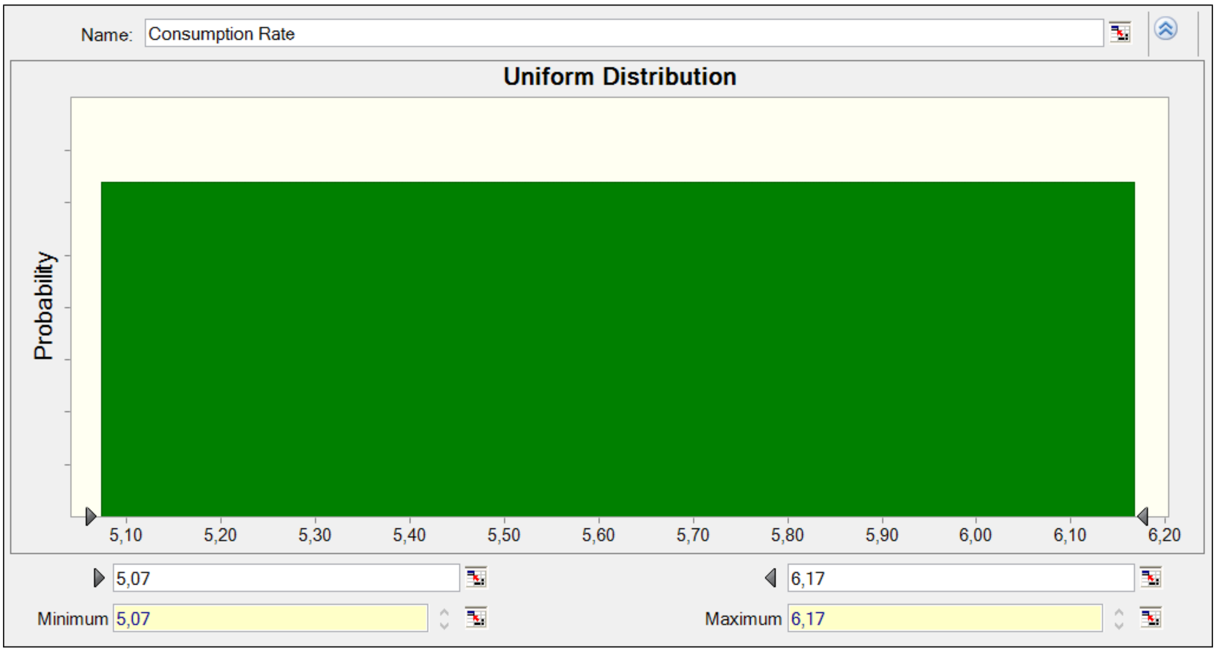
45,70

53,40

Minimum 45,70

Maximum 53,40

Fig.A.39. Input distribution of the background As concentrations of Radish



Name: Consumption Rate

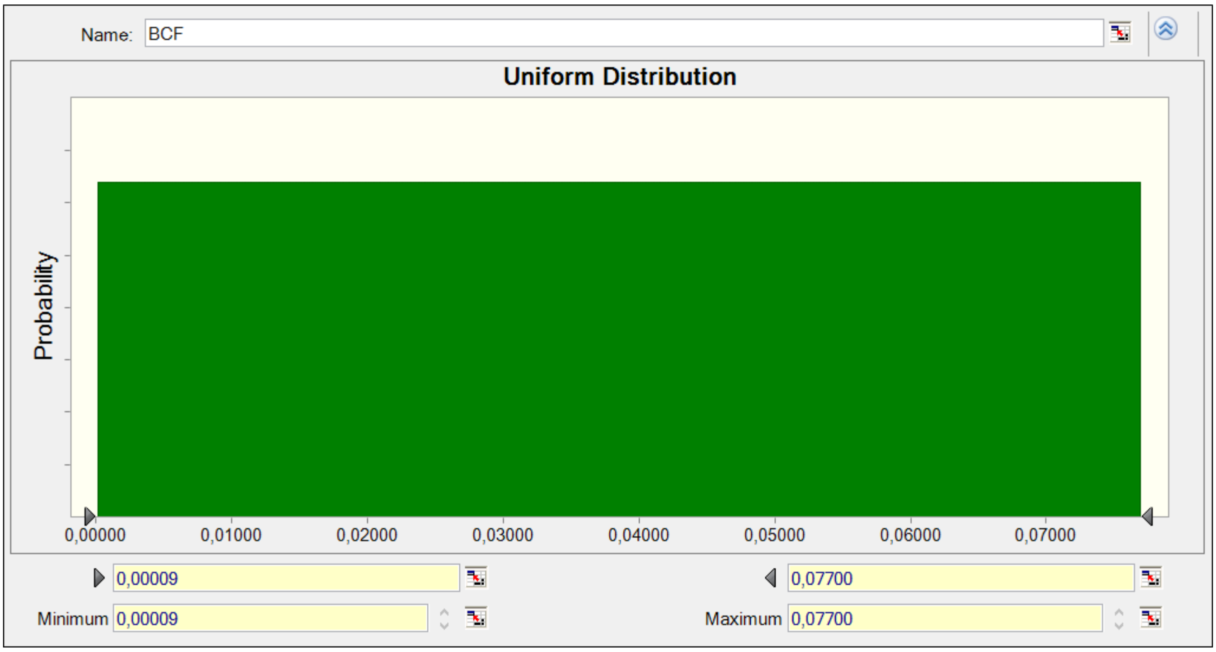
5,07

6,17

Minimum 5,07

Maximum 6,17

Fig.A.40. Input distribution of the consumption rates of Radish

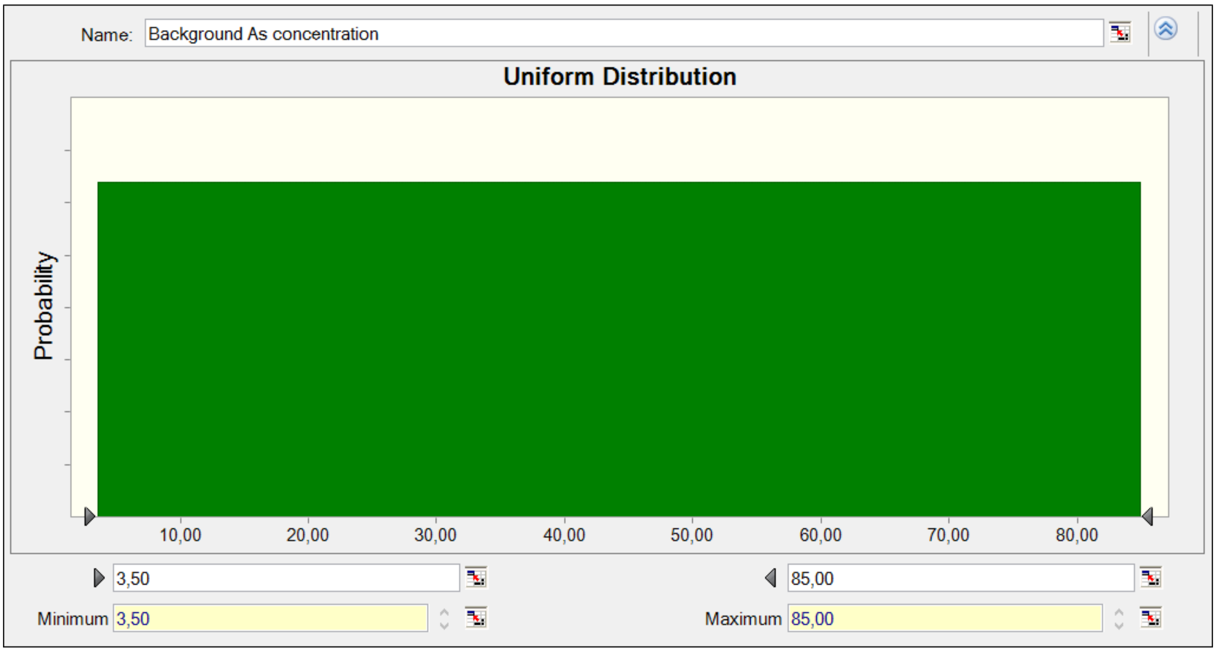


Name: BCF

▷ 0,00009 ◁ 0,07700

Minimum 0,00009 Maximum 0,07700

Fig.A.41. Input distribution of the bioconcentration factors of Spinach

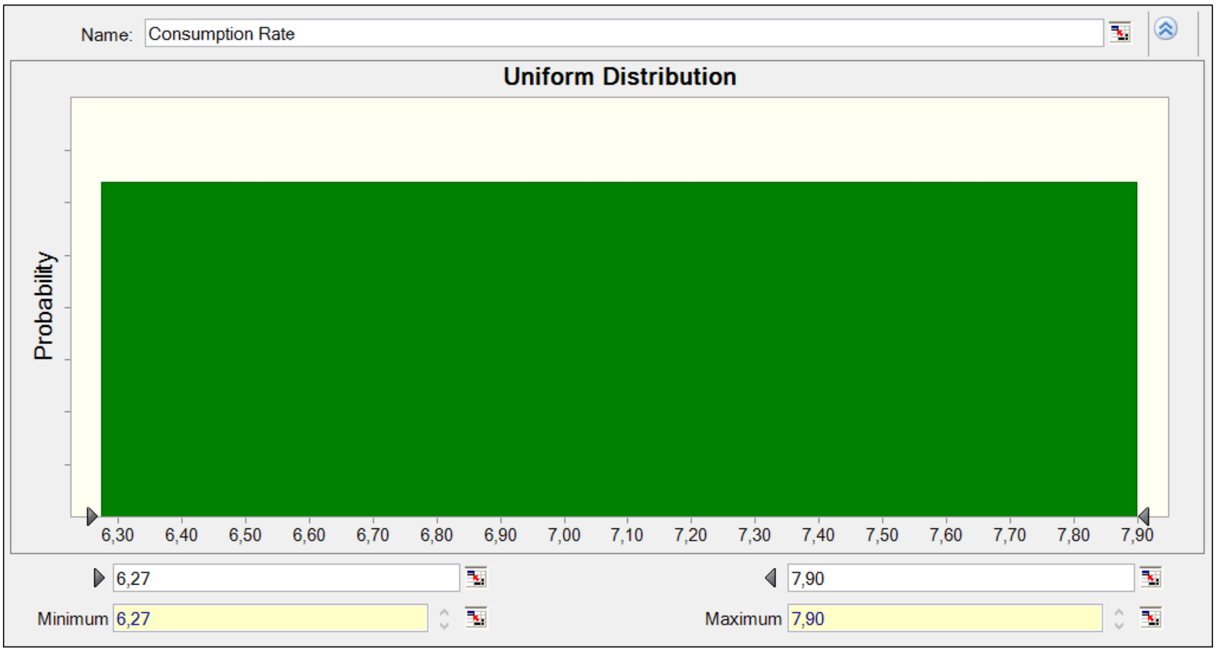


Name: Background As concentration

▷ 3,50 ◁ 85,00

Minimum 3,50 Maximum 85,00

Fig.A.42. Input distribution of the background As concentrations of Spinach



Name: Consumption Rate

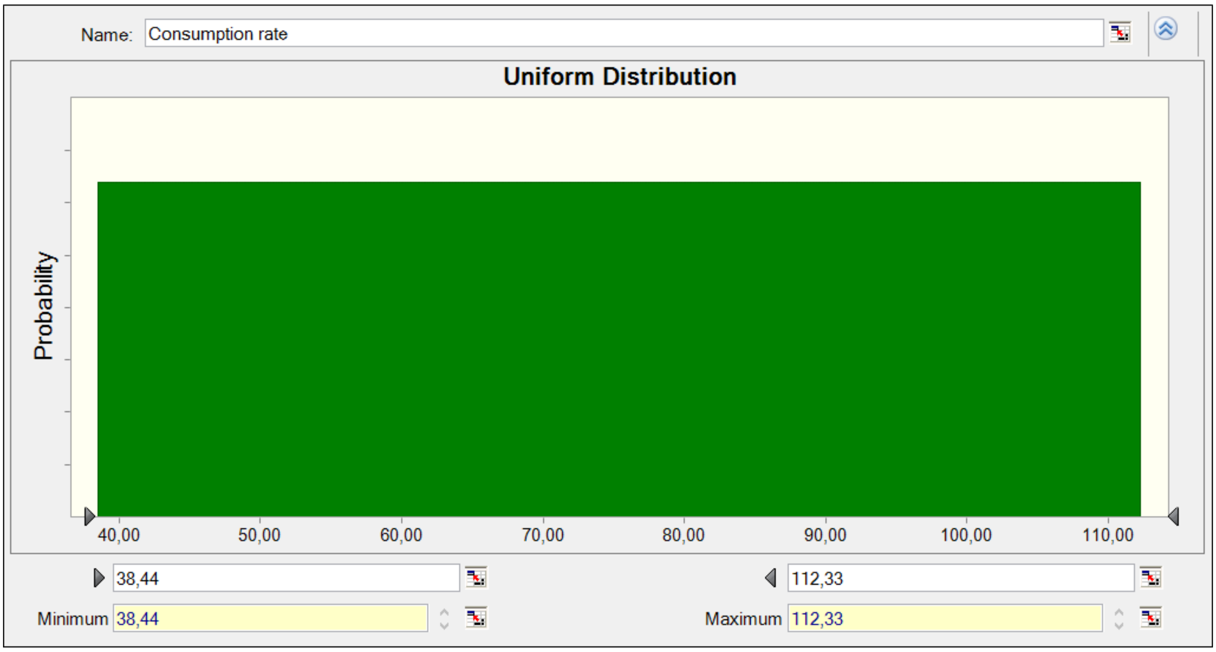
6,27

7,90

Minimum 6,27

Maximum 7,90

Fig.A.43. Input distribution of the consumption rates of Spinach



Name: Consumption rate

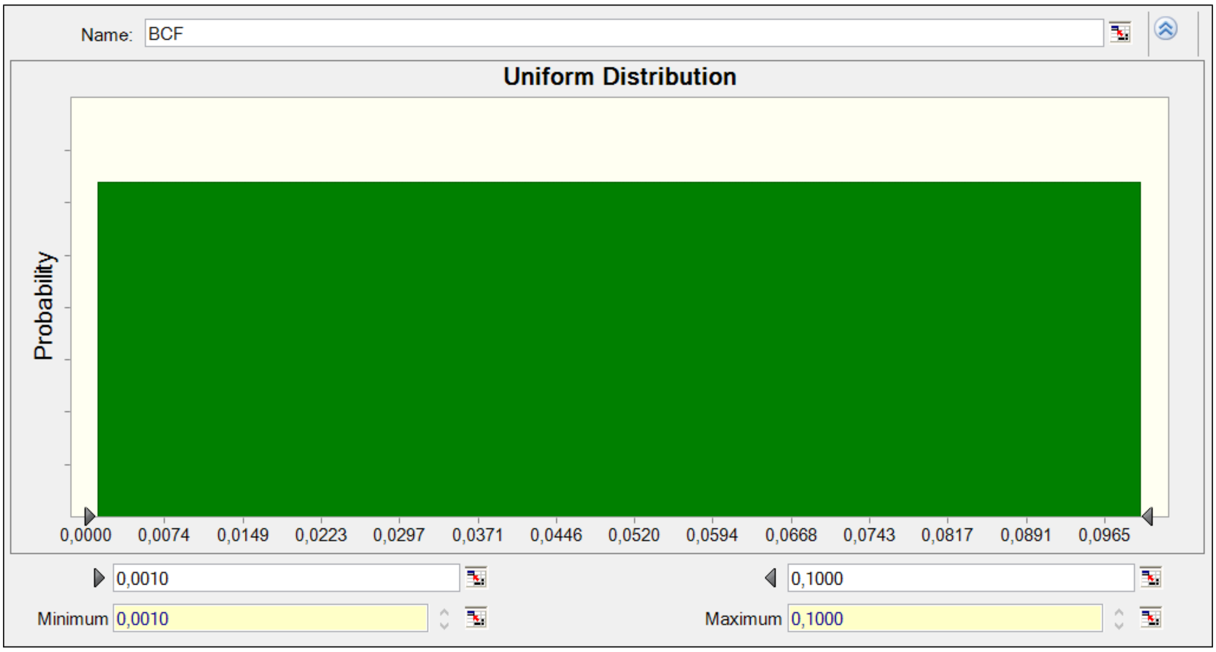
38,44

112,33

Minimum 38,44

Maximum 112,33

Fig.A.44. Input distribution of the consumption rates of Sunflower Seed



Name: BCF

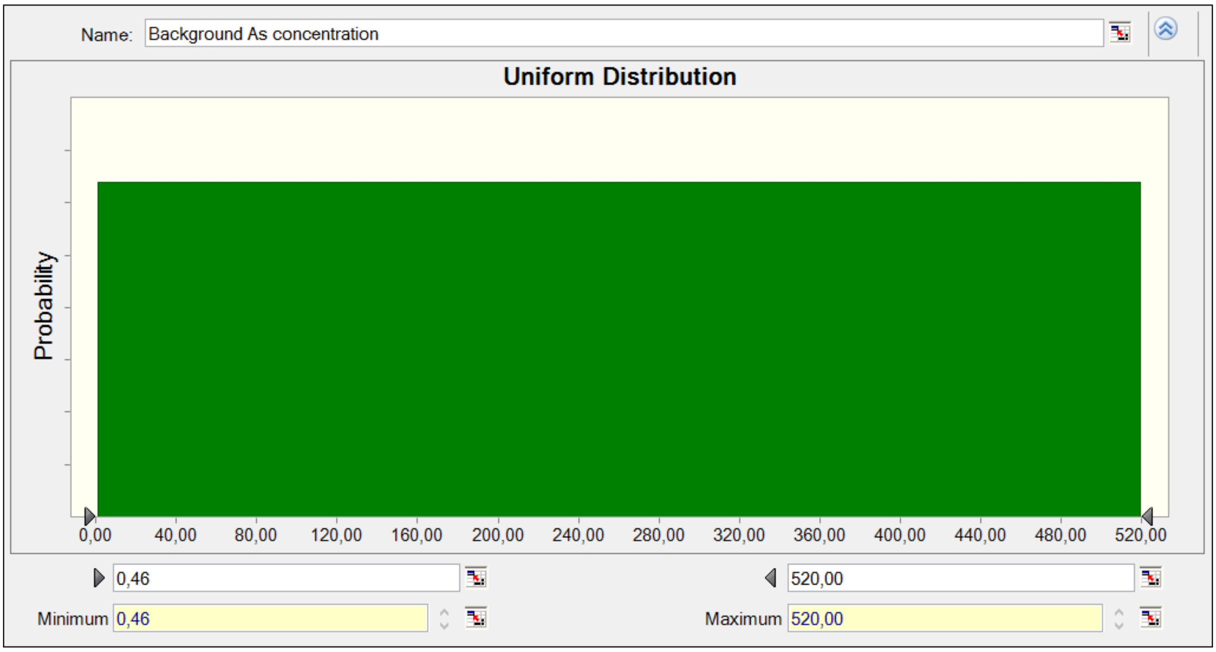
0,0010

0,1000

Minimum 0,0010

Maximum 0,1000

Fig.A.45. Input distribution of the bioconcentration factors of Tomato



Name: Background As concentration

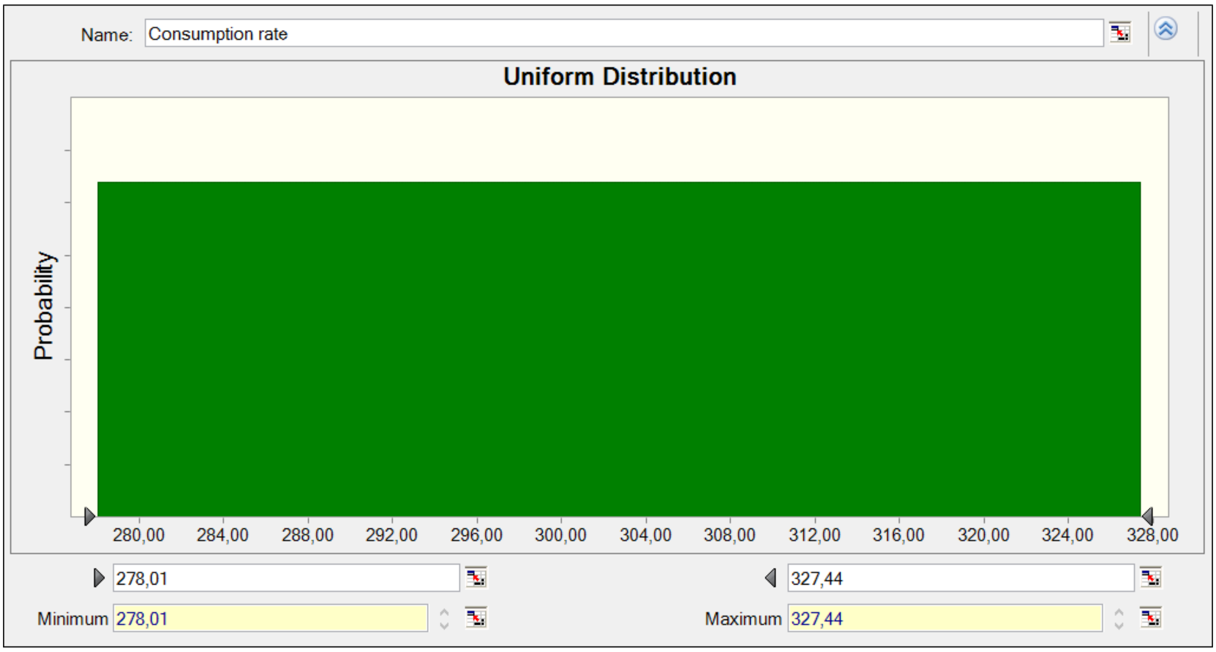
0,46

520,00

Minimum 0,46

Maximum 520,00

Fig.A.46. Input distribution of the background As concentrations of Tomato



Name: Consumption rate

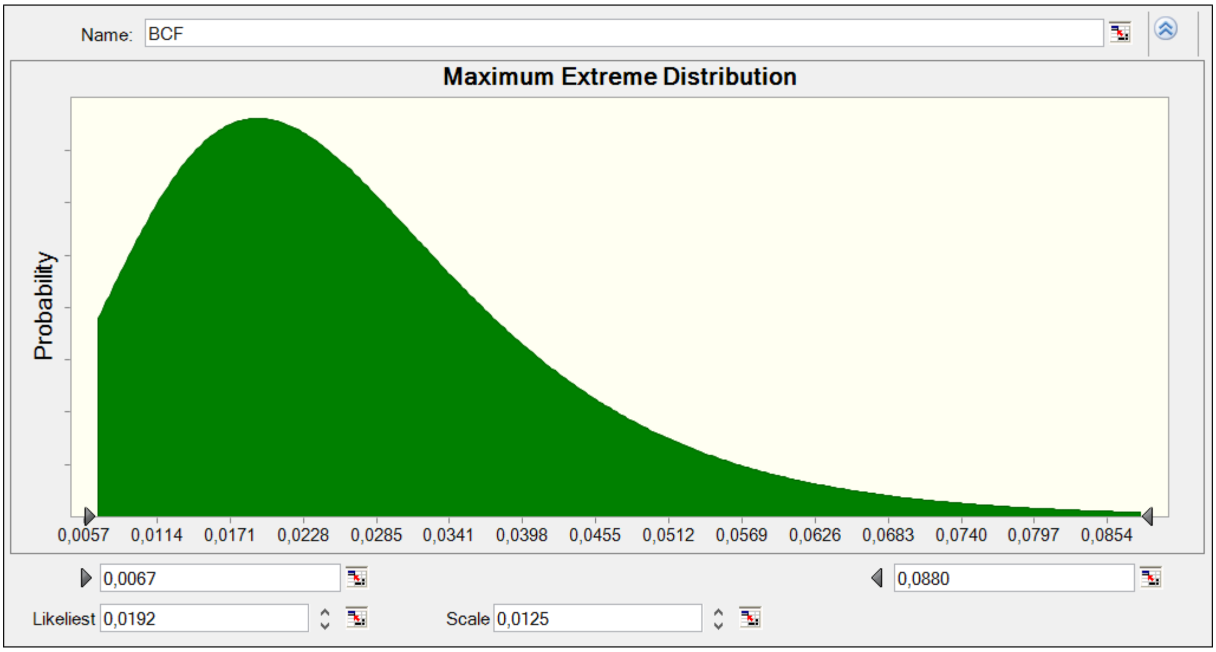
278,01

327,44

Minimum 278,01

Maximum 327,44

Fig.A.47. Input distribution of the consumption rates of Tomato



Name: BCF

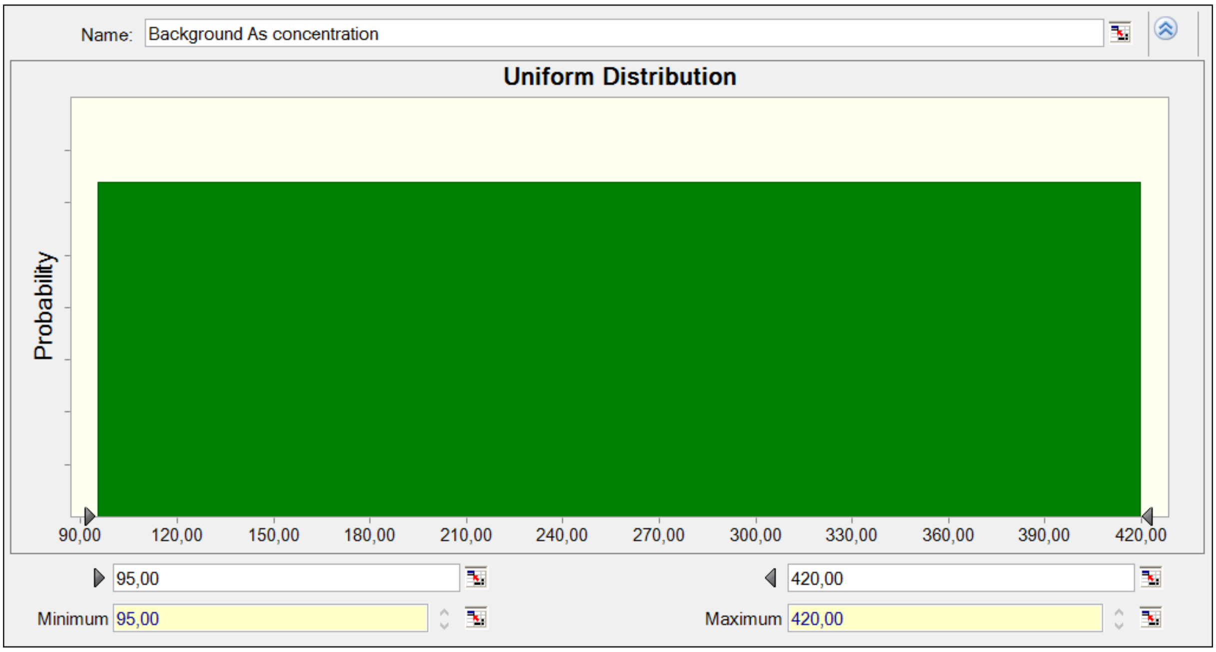
0,0067

0,0880

Likeliest 0,0192

Scale 0,0125

Fig.A.48. Input distribution of the bioconcentration factors of Wheat



Name: Background As concentration

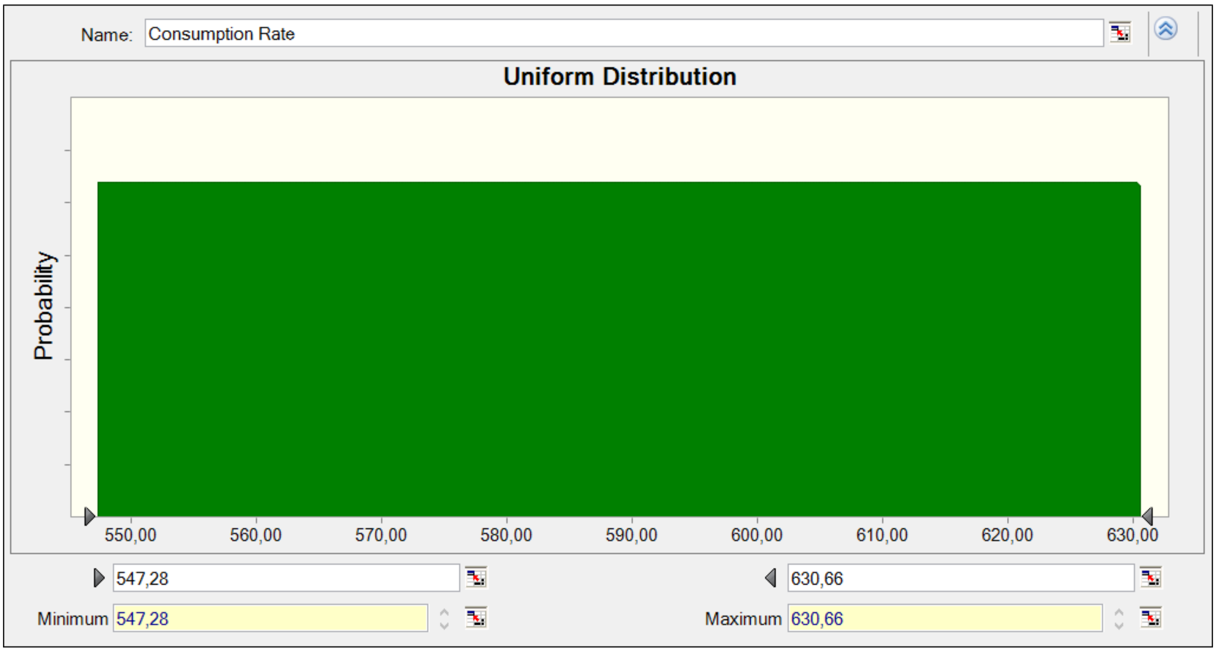
95,00

420,00

Minimum 95,00

Maximum 420,00

Fig.A.49. Input distribution of the background As concentrations of Wheat



Name: Consumption Rate

547,28

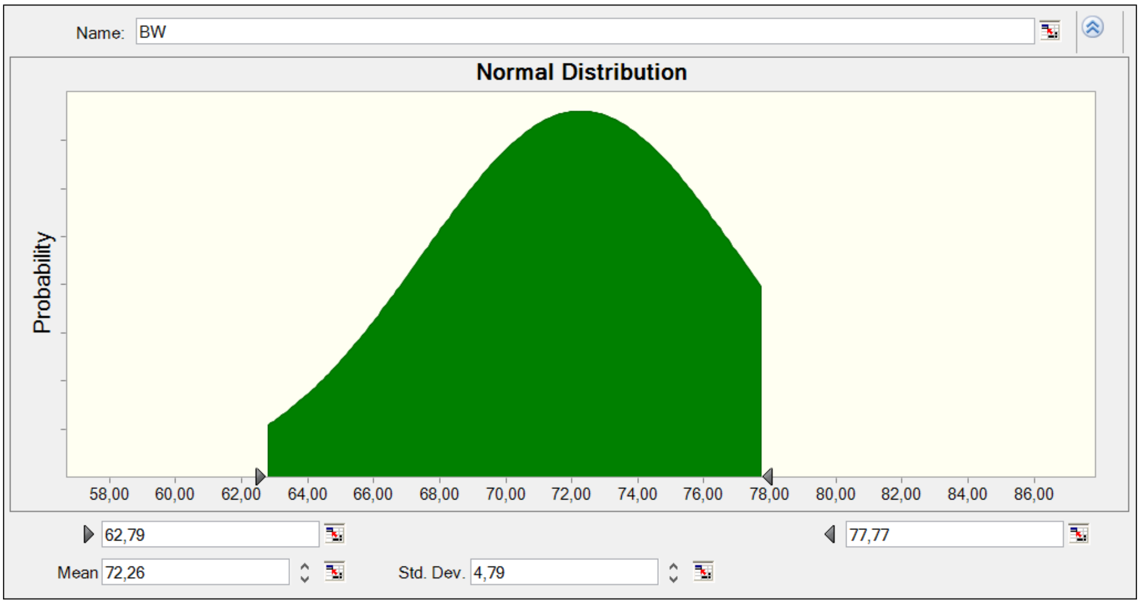
630,66

Minimum 547,28

Maximum 630,66

Fig.A.50. Input distribution of the consumption rates of Wheat

A.2. Input Distributions Used in The Probabilistic Approach of Simav District



Name: BW

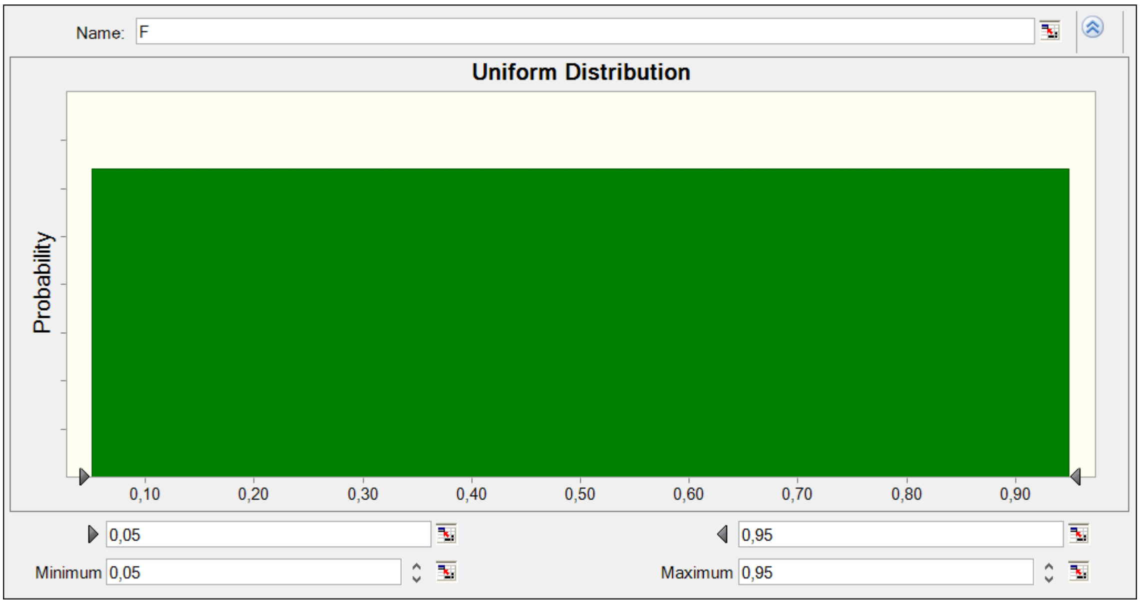
62,79

77,77

Mean 72,26

Std. Dev. 4,79

Fig.A.51. Input distribution of the Body Weight



Name: F

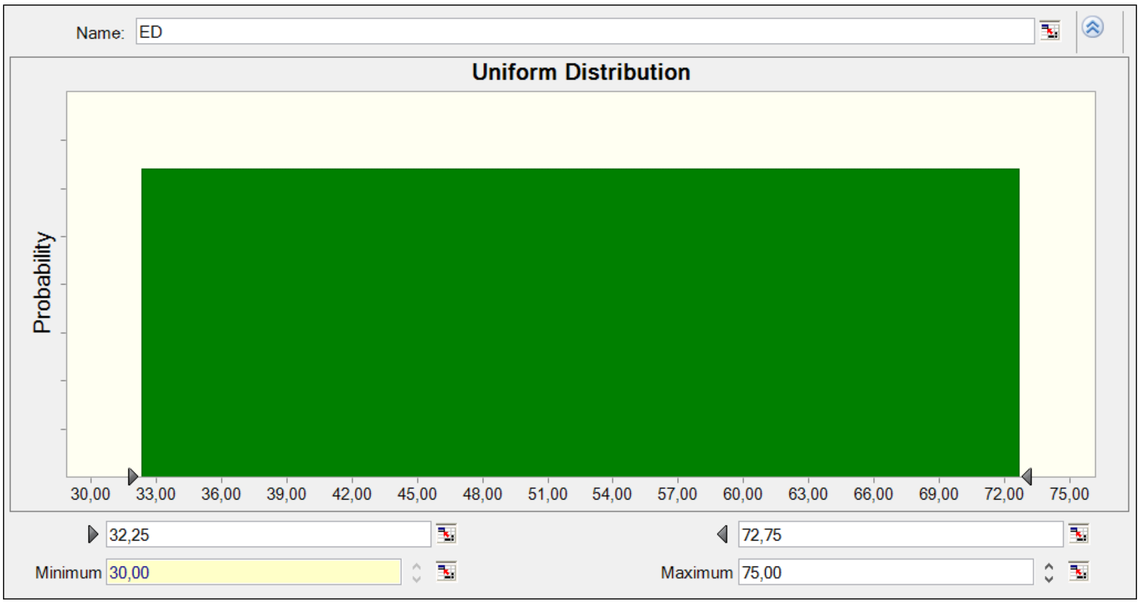
0,05

0,95

Minimum 0,05

Maximum 0,95

Fig.A.52. Input distribution of the consumption ratio from contaminated source



Name: ED

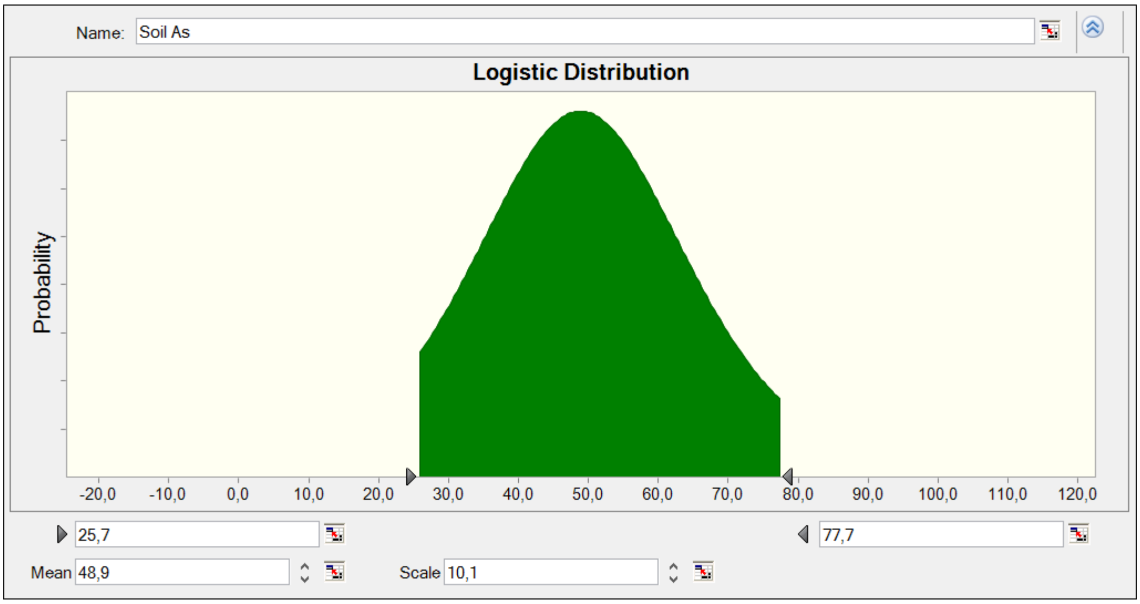
32,25

72,75

Minimum 30,00

Maximum 75,00

Fig.A.53. Input distribution of the exposure duration for carcinogenic risk assessment



Name: Soil As

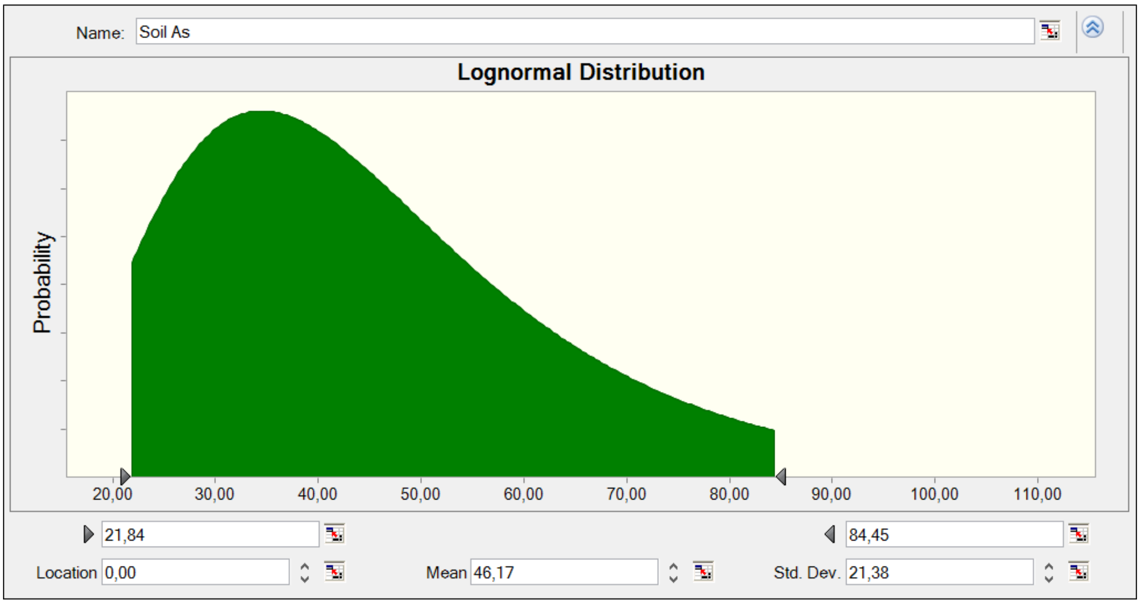
25,7

77,7

Mean 48,9

Scale 10,1

Fig.A.54. Input distribution of the soil arsenic concentrations for the plants with one meter root depth



Name: Soil As

21,84

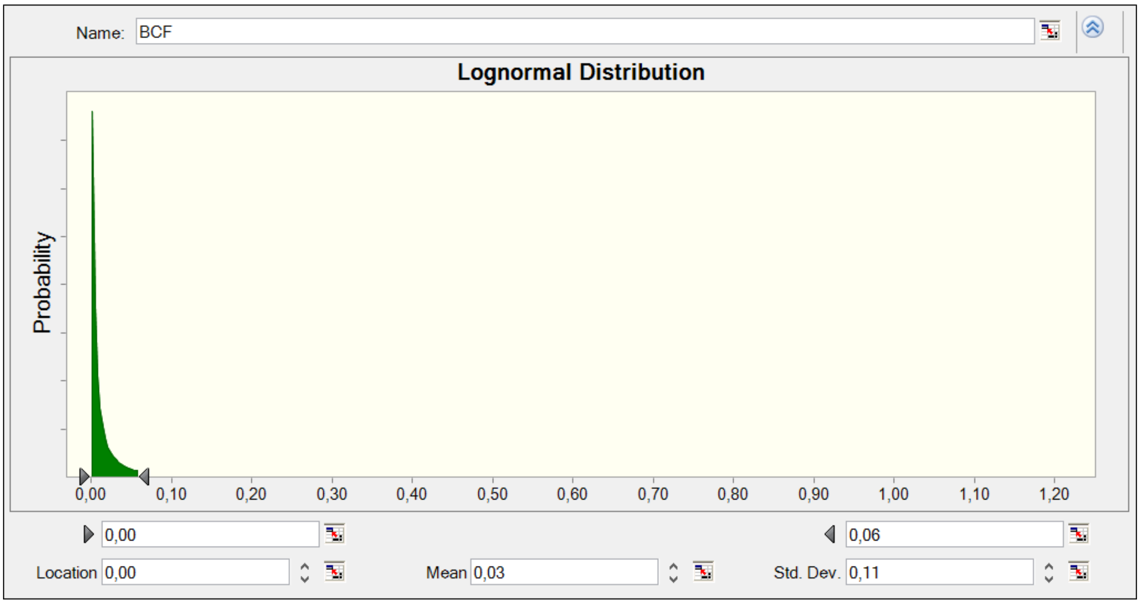
84,45

Location 0,00

Mean 46,17

Std. Dev. 21,38

Fig.A.55. Input distribution of the soil arsenic concentrations for the plants with one to five meters root depth



Name: BCF

0,00

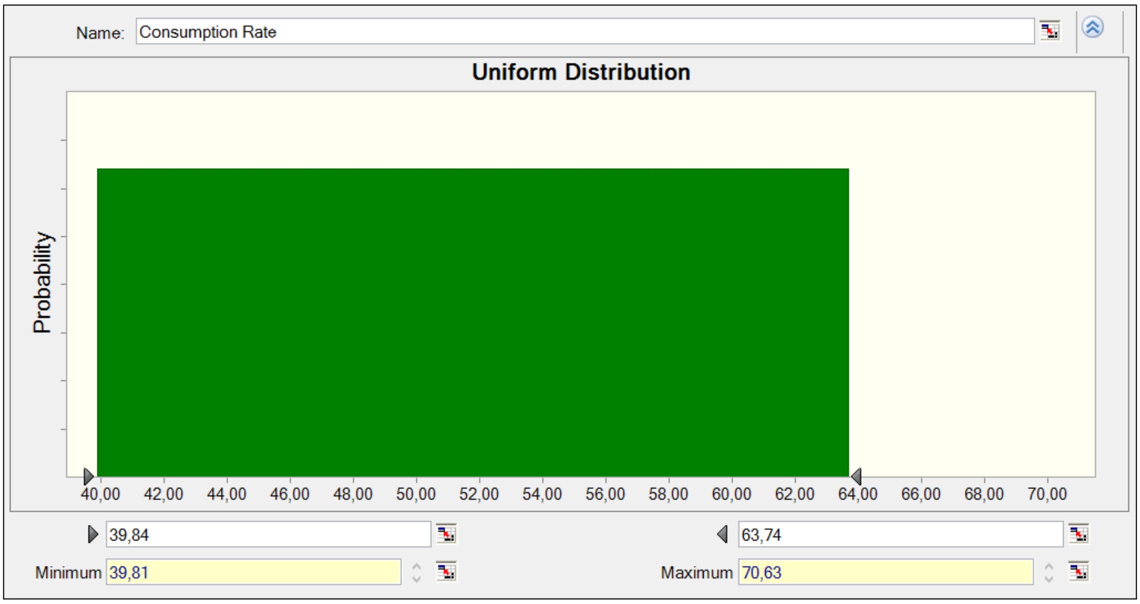
0,06

Location 0,00

Mean 0,03

Std. Dev. 0,11

Fig.A.56. Input distribution of the bioconcentration factors of Corn



Name: Consumption Rate

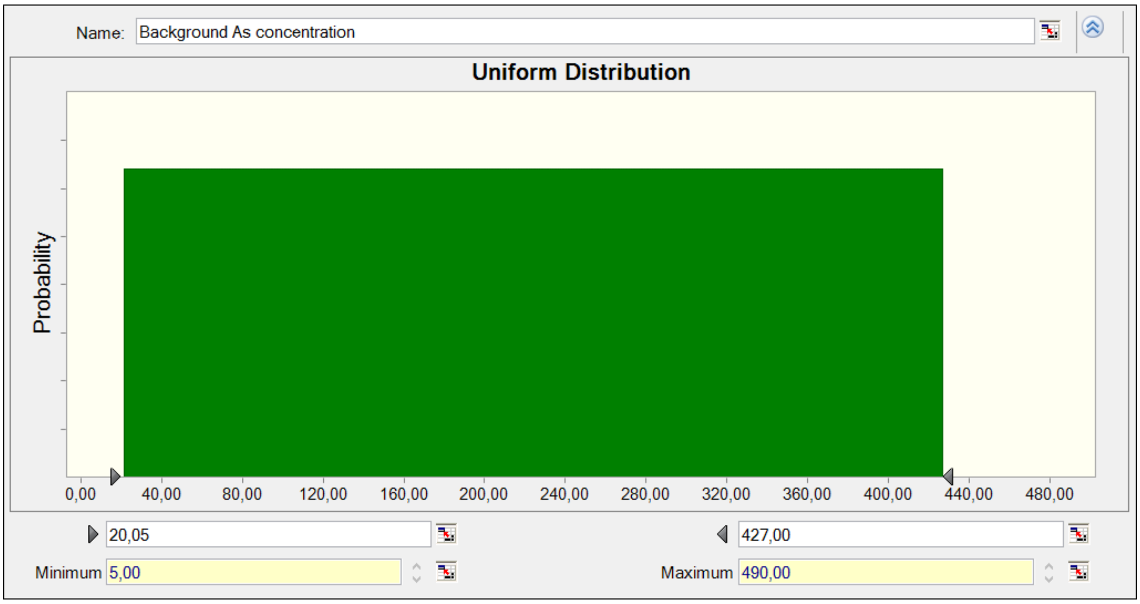
39,84

63,74

Minimum 39,81

Maximum 70,63

Fig.A.57. Input distribution of the consumption rates of Corn



Name: Background As concentration

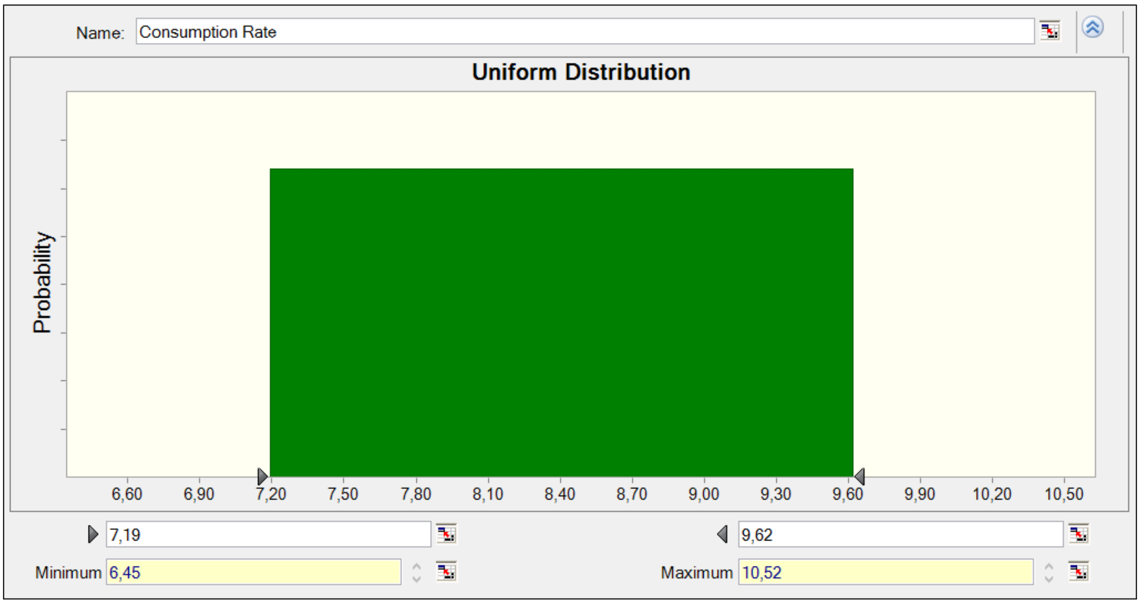
20,05

427,00

Minimum 5,00

Maximum 490,00

Fig.A.58. Input Distribution of the background As concentrations of Bean


Name: Consumption Rate

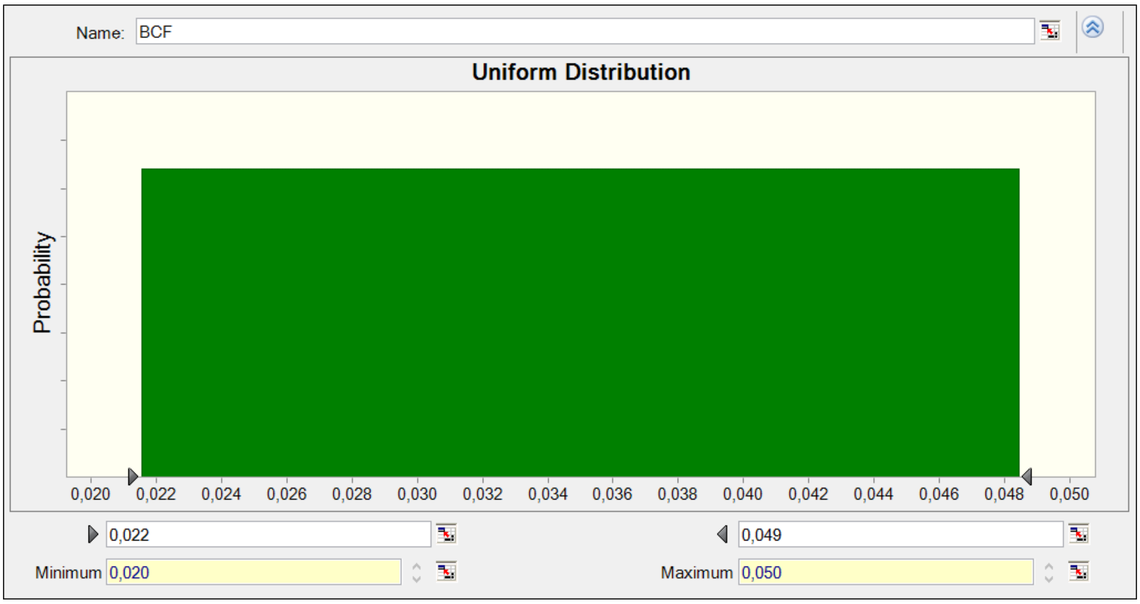
7,19

9,62

Minimum 6,45

Maximum 10,52

Fig.A.59. Input Distribution of the consumption rates of Bean


Name: BCF

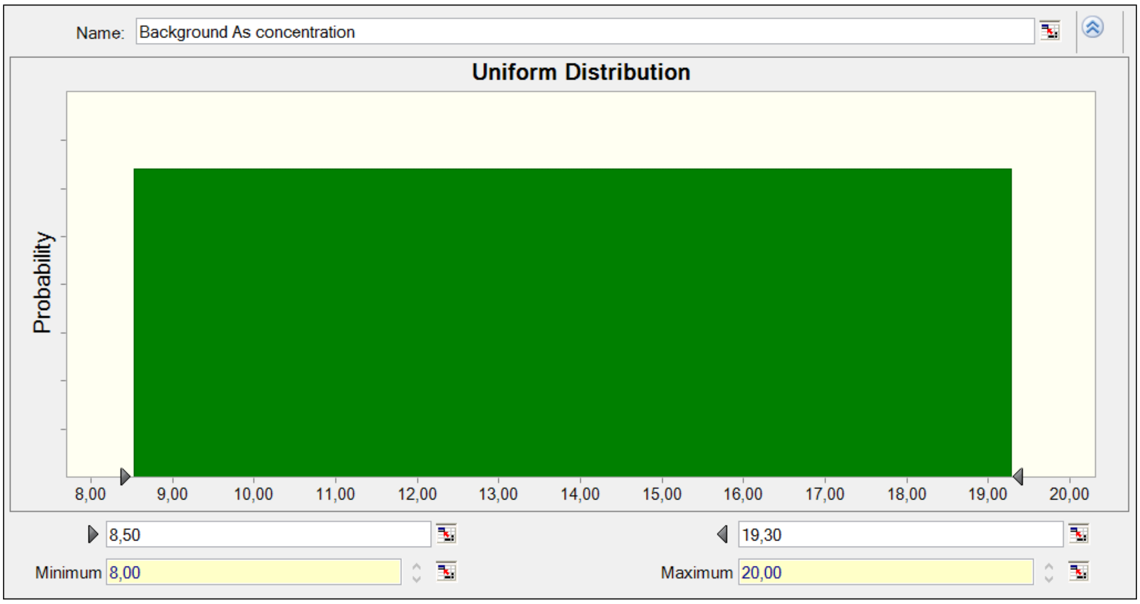
0,022

0,049

Minimum 0,020

Maximum 0,050

Fig.A.60. Input distribution of the bioconcentration factors of Garlic



Name: Background As concentration

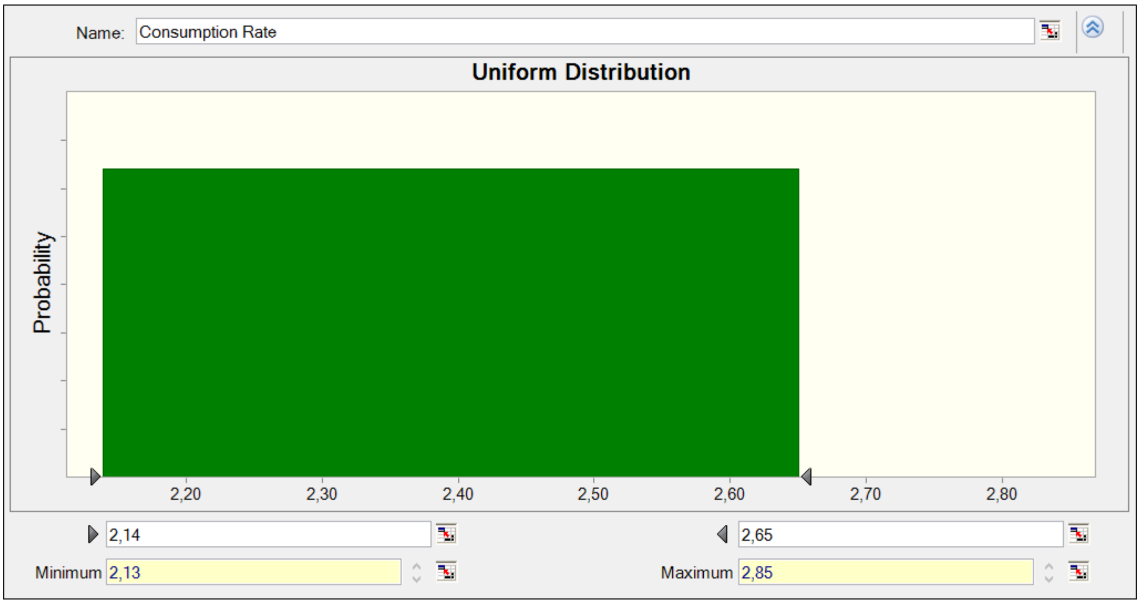
8,50

19,30

Minimum 8,00

Maximum 20,00

Fig.A.61. Input distribution of the background As concentrations of Garlic



Name: Consumption Rate

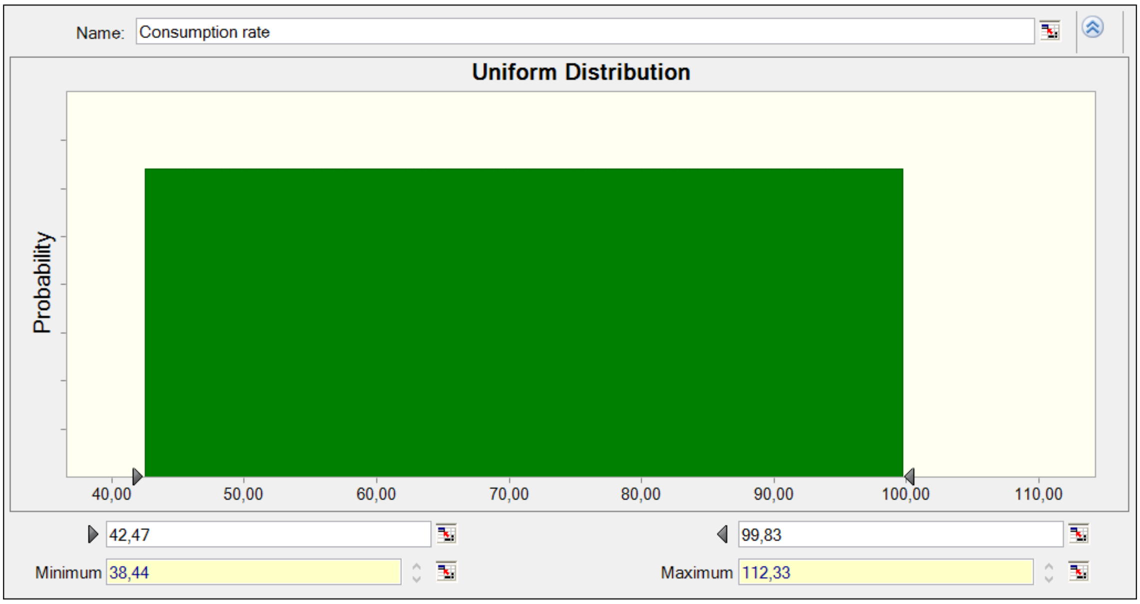
2,14

2,65

Minimum 2,13

Maximum 2,85

Fig.A.62. Input distribution of the consumption rates of Garlic



Name: Consumption rate

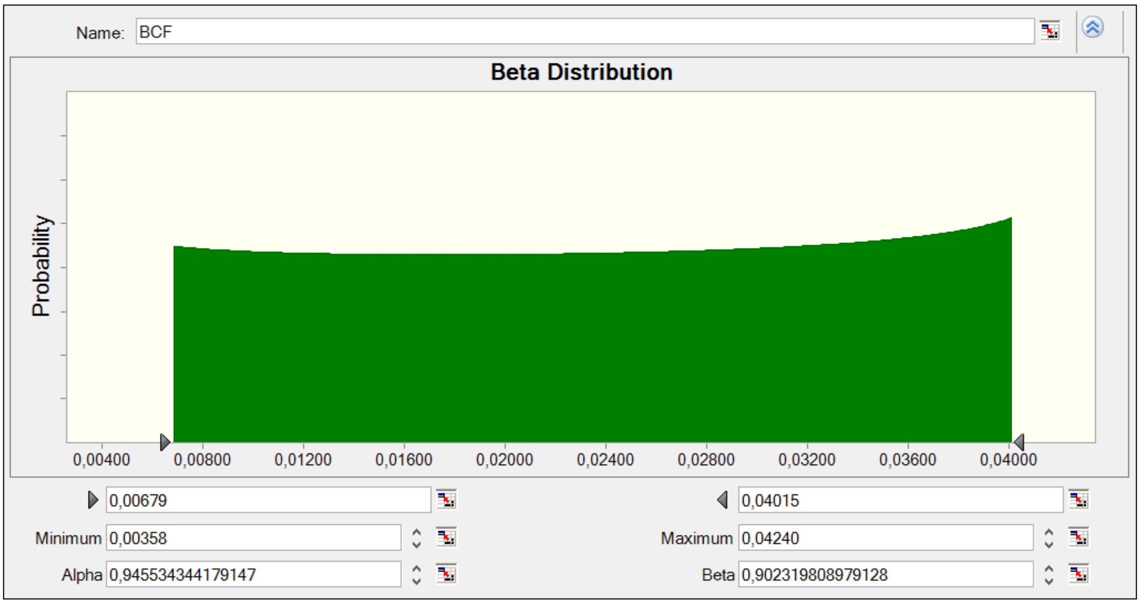
42,47

99,83

Minimum 38,44

Maximum 112,33

Fig.A.63. Input distribution of the consumption rates of Sunflower



Name: BCF

0,00679

0,04015

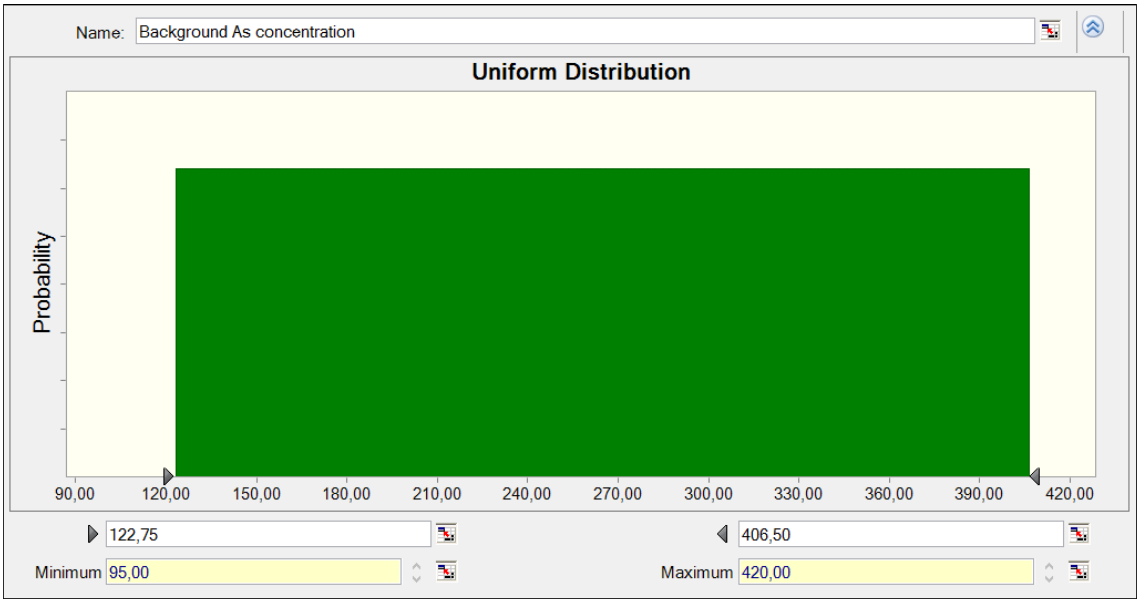
Minimum 0,00358

Maximum 0,04240

Alpha 0,945534344179147

Beta 0,902319808979128

Fig.A.64. Input distribution of the bioconcentration factors of Wheat


Name: Background As concentration

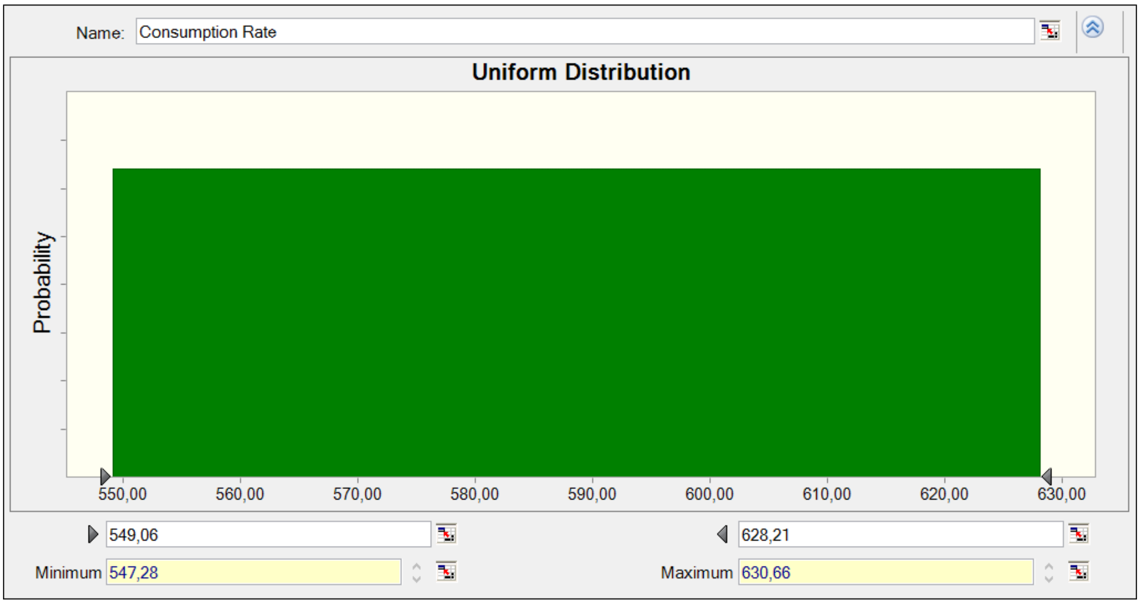
122,75

406,50

Minimum 95,00

Maximum 420,00

Fig.A.65. Input distribution of the background As concentrations of Wheat


Name: Consumption Rate

549,06

628,21

Minimum 547,28

Maximum 630,66

Fig.A.66. Input Distribution of the consumption rates of Wheat