Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences

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– based on Swedish Market basket data 1999-2015

Fosforintag i Sverige

– skattat från Matkorgen data 1999-2015

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Department of Molecular Sciences
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Abstract

Concerns regarding excessive phosphorus intake has been raised in the USA due to an increased usage of phosphorus containing additives in the food industry. Phosphorus containing additives (inorganic phosphorus) are for example found in processed meat and cola-flavoured soft drinks. An excessive phosphorus intake might have severe consequences on health since the risk of cardiovascular diseases, chronic kidney disease and osteoporosis increases with increasing serum phosphorus concentrations. The intake of inorganic phosphorus is especially interesting since inorganic phosphorus has a higher absorption rate. However, the proportion of inorganic phosphorus is difficult to estimate. The aim of this study was to estimate the total phosphorus intake, intake of inorganic phosphorus and the ratio between calcium and phosphorus. The daily phosphorus intake in Sweden was estimated from Market basket studies performed by the National Food Agency. Food items were analysed and together with per capita consumption the phosphorus intake was estimated. Between 1999 and 2015, phosphorus intake in the Swedish population constantly was about 1800-2000 mg/day. An increasing trend has not been observed in Sweden, rather a decrease (p=0.006) between 2005 and 2015. Estimations show that the Market basket 2015 contains a maximum of 400 mg inorganic phosphorus. The three main phosphorus sources are dairy products (32%), cereals (21%) and meat (21%). The calcium to phosphorus ratio in 2015 was estimated to be 1:2.1 and has not increased substantially since 1999. Although there is no increase in phosphorus intake in Sweden, the phosphorus intake is three times higher than recommended intakes, hence further monitoring is required since consequences of an excessive phosphorus intake might be serious.

Keywords: phosphorus intake, Market basket study, calcium to phosphorus ratio, inorganic phosphorus, additives

Sammanfattning

Det ökade fosforintaget i USA till följd av en ökad användning av livsmedelstillsatser innehållande fosfor har skapat oro på olika håll, även i Sverige. Tillsatser innehållande fosfor återfinns bland annat i processade köttprodukter och i läskedrycker med colasmak. Ett alltför höft fosforintag kan få allvarliga konsekvenser för hälsan, eftersom risken för hjärt- och kärlsjukdomar, kronisk njurfunktion och osteoporos ökar med förhöjda fosforkoncentrationer i blodet. Intaget av oorganiskt fosfor är speciellt intressant eftersom oorganiskt fosfor har en högre absorptionshastighet. Andelen oorganiskt fosfor är emellertid svår att uppskatta. Syftet med denna studie var att uppskatta det totala fosforintaget, intaget av oorganiskt fosfor och förhållandet mellan kalcium och fosfor. Det dagliga fosforintaget i Sverige uppskattas från Matkorgen-studier som utförs av Livsmedelsverket. Livsmedel analyserades och tillsammans med per capita konsumtion från Jordbruksverket uppskattades fosforintaget. Mellan 1999–2015 var fosforintaget i Sverige ca 1800-2200 mg/dag. En ökande trend kan inte ses i Sverige, snarare en minskande trend (p=0,006) mellan 2005 och 2015. Uppskattningar visar att Matkorgen 2015 innehåller maximalt 400 mg oorganiskt fosfor. De tre huvudsakliga fosforkällorna är mejeriprodukter (32 %), spannmål (21%) och kött (21%). Kalcium- till fosforförhållandet uppskattades 2015 till 1:2,1 och har inte ökat väsentligt sedan 1999. Trots att det inte finns någon ökande trend av fosforintaget i Sverige är fosforintaget tre gånger högre än det rekommenderade intaget, vilket innebär att fosfor intaget även i fortsättningen bör övervakas eftersom konsekvenserna av ett allt för stort fosforintag är mycket allvarliga.

Nyckelord: fosforintag, Matkorgen, kalcium till fosforförhållande, oorganiskt fosfor, tillsatser

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Abbreviations

1,25-$(OH)_2D_3$	Calcitriol (active metabolite of vitamin D)
ADP	Adenosine diphosphate
AI	Adequate Intake
AMP	Adenosine monophosphate
ATP	Adenosine triphosphate
CKD	Chronic kidney disease
CP	Creatine phosphate
CV	Coefficient of variation
CVD	Cardiovascular disease
DRVs	Dietary Reference Values
ECV	Extracellular volume
EFSA	European Food Safety Authority
FGF-23	Fibroblast Growth Factor 23
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICV	Intracellular volume
LOD	Limit of detection
LOQ	Limit of quantification
MB	Market Basket
NaPi-2a/b/c	Sodium phosphate cotransporter-2a-c
NFA	National Food Agency
NHANES	National Health and Nutrition Education Surveys in the USA
NNR	Nordic Nutrition Recommendations
PTH	Parathyroid hormone
RI	Recommended intake (by NNR)
SD	Standard deviation
UL	Tolerable Upper level

1 Background

1.1 Introduction

Phosphorus is a non-metal chemical element belonging to the nitrogen group of the periodic table. It is a highly reactive chemical element and therefore does not occur in nature as a free element but as inorganic phosphate (PO_4) rocks and as part of many minerals. The name of the salt created from phosphorus is phosphate. The majority of phosphorus in the human body is found in the form of hydroxyapatite [$Ca_{10}(OH)_2(PO_4)_6$] in bone and teeth, the rest is found in organs and extracellular fluid (EFSA, 2015; Kalantar-Zadeh *et al.*, 2010). Recommended intakes of minerals for optimal health often include a lower and safe upper intake limits. Intake below lower limit can lead to a risk to develop mineral deficiency and an excessive intake (above upper intake level) can lead to an increased risk of an adverse or toxic effect (NNR, 2014). In case of phosphorus, it is more likely nowadays to get symptoms of excessive intake of phosphorus rather than phosphorus deficiency (Calvo & Park, 1996). Several prospective observational studies based on the general population have indicated an association between high phosphorus intake and several diseases, such as cardiovascular disease (CVD) and chronic kidney disease (CKD) (Stenvinkel et al., 2014). Concerns have therefore been raised that overconsumption of phosphorus due to phosphorus containing additives added to food is possibly causing a public health disease. The food industry is blamed for contributing to an increased phosphorus intake among the population (Stenvinkel *et al.*, 2014; Foley, 2009).

Moreover sustainability of phosphorus use for fertilizer production is also discussed. A large amount of phosphorus is mined every year to produce fertilizers but a large portion ends up in rivers and oceans, causing eutrophication (Elser, 2012). Scientists are debating about the size of the phosphorus resource and discusses when “peak-phosphorus” will be reach (Cordell et al., 2009). The food industry is also accused for contributing to the eutrophication by emissions of excess phosphorus containing additives to waste water. The unnecessary food waste occurring at different level of the food chain ranging from industry, restaurants, retailers and households of course also contributes to the problematic surrounding phosphorus (Swedish Institute for the Marine Environment, 2016).

1.2 The role of phosphorus in the human body

Phosphorus is essential to life in several different ways and the second most abundant mineral in human bodies, representing about 1% of the total body weight (Calvo & Lamberg-Allardt, 2015). The total phosphorus content in a 70 kg human is about 700-800 mg (Bansal, 1990). Phosphorus is present in different forms in the body. Serum mainly contains inorganic phosphates (dihydrogen and monohydrogen phosphate), bone phosphorus is present either as bound to collagen or in the form of the mineral hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), while soft tissues and extracellular fluids mainly organic phosphates in complex with carbohydrates, lipids or proteins (Elser, 2012; Bansal, 1990). 85% of the total body phosphorus content is found in bone and teeth. About 10% of the phosphorus content is found in muscle, nervous system, skin and other organs and less than 1% is located in the extra cellular fluid (Abrahamsson et al., 2013). Out of the serum phosphate about 10-15% is protein bound and 85-90% free and ultrafiltrable. Serum inorganic phosphate stands for only a minor part of the total body content but it is easy to measure and gives an estimation of the storage status. Children normally have a higher concentration then adults. In addition to age dependence, serum concentration of inorganic phosphate is affected by dietary intake and acid-base status. Phosphate occurs in two different forms in serum, dihydrogen phosphate (H_2PO_4) and its salt mono-hydrogen phosphate (HPO_4) (Bansal, 1990).

1.2.1 Intracellular and extracellular functions of phosphorus

Phosphorus serves a variety of functions. Cell membranes are composed of phospholipid molecules, which due to its negative charge contribute to the repulsive forces that organize the membrane into lipid bilayers (Elser, 2012). Phosphorus is also involved in the cell energy cycle as part of the adenosine triphosphate (ATP), adenosine diphosphate (ADP), and adenosine monophosphate (AMP) molecules. The energy released from carbohydrates, fat and proteins through catabolism is stored by binding phosphate to ADP to build ATP or to creatine to form creatine phosphate (CP) (Abrahamsson et al., 2013). To reload AMP to ATP via ADP, which is crucial to maintain vitality, a constant supply of PO_4 is essential (EFSA, 2015;

Elser, 2012). ATP and CP are essential for muscle contractions, neurological functions and the electrolyte transport.

Phosphorus is also necessary for enzymatic processes. Phosphorylation of glucose and proteins is crucial for various transport mechanisms and metabolic processes such as glycolysis, oxidative phosphorylation and urea cycle. Several vitamins such as thiamine (B_1) and pyridoxine (B_6) are activated through phosphorylation. Phosphorylation also affects the oxygen-carrying capacity of haemoglobin. Phosphorus has a regulatory role since the red blood cells depend on phosphate to create 2,3-diphosphoglycerate (Bansal, 1990). Ferritins are phosphoproteins essential for iron storage (Miller, 1996). Phosphorus is present as phosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) in the body fluids and are involved in acid-base regulation since HPO_4^{2-} bind hydrogen ions and create $H_2PO_4^-$ both intra cellular and in blood. Exchange of phosphate between intracellular volume (ICV) and extracellular volume (ECV) occurs by passive transport across cell membranes (Abrahamsson et al., 2013). Phosphorus also has a central role when it comes to storing and processing of genetic information since phosphate is a structural component of the nucleic acid DNA and RNA (EFSA, 2015; Elser, 2012). Phosphorus atoms contribute with about 9% of the mass of the nucleic acids, DNA and RNA (Sterner & Elser, 2002).

1.2.2 Mineralisation of bones and teeth

Out of the phosphorus found in the human body 85% of the content is found in bone and teeth either as phosphate bound to collagen or as inorganic hydroxyapatite (Abrahamsson et al., 2013). Phosphorus and calcium account for 80-90% of bone catabolism and hydroxyapatite forms a mineralized matrix which provides special features to bone (EFSA, 2015). Phosphate is necessary for a normal skeletal maturity since collagen and collagen fibrils are phosphorylated. The phosphorus stored in skeleton is utilized when dietary phosphorus supply is low (Abrahamsson et al., 2013).

1.3 Phosphorus homeostasis

It has been known for over 40 years that dogs fed with phosphate supplements in excess develops secondary hyperparathyroidism, bone loss and calcification of soft tissue (Laflamme & Jowsey, 1972). With new knowledge, the interest in phosphorus has returned. The endocrine regulation of phosphorus is now better understood and also how the balance is disrupted with an excess intake of phosphorus (Quarles, 2008). Inorganic phosphate is rapidly absorbed across the small intestine causing a rise in blood phosphate levels (Razzaque, 2011). Out of the extracellular unbound inorganic phosphate (PO_4^-) only 1% is metabolically active and maintained within the serum concentration range 2.5-4.5 mg/dL. The concentration is maintained tightly by keeping net phosphorus absorption equivalent to urinary losses but also the deposited and resorbed amounts from bone equal. There is a complex organ network system behind the serum phosphorus homeostasis, involving bone, kidney and intestine regulated by parathyroid hormone (PTH) and vitamin D (Calvo & Lamberg-Allardt, 2015). Figure 1 shows a rough estimate of the phosphorus absorption and distribution for an adult with a phosphorus intake of 1000 mg/day.

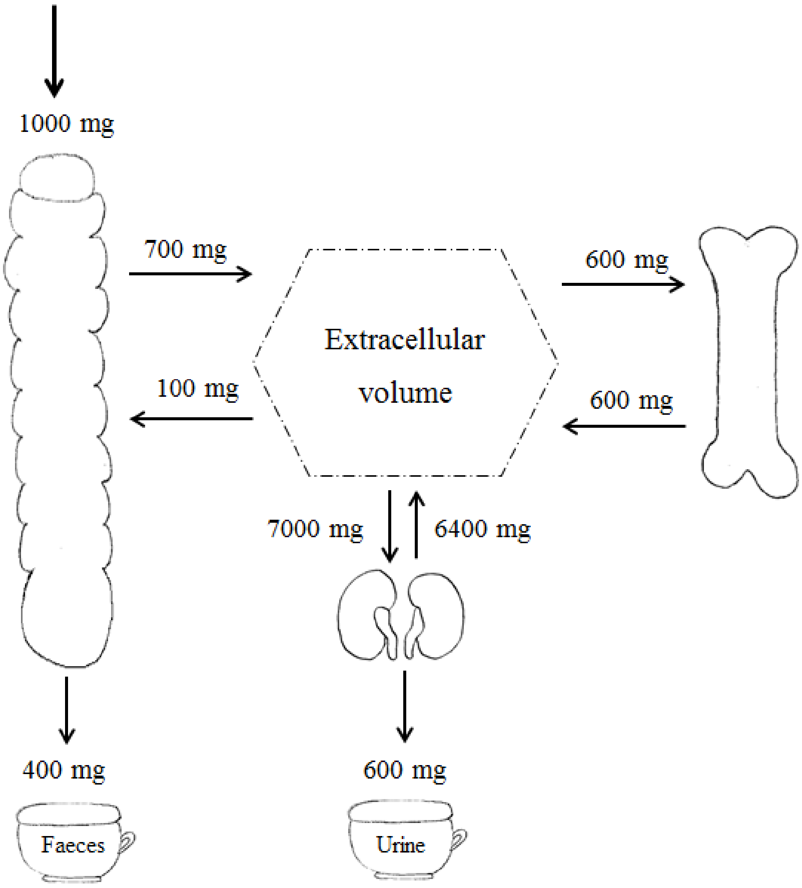

Figure 1. *Phosphorus absorption and distribution. A rough estimate of the metabolism for adults with a phosphorus intake at 1000 mg/day. The values are approximate numbers and the variations between individuals are large. With inspiration from (Abrahamsson et al., 2013).*

Dietary organic phosphate is digested to inorganic bound phosphate. The absorption in the gastrointestinal tract is about 55-70% for adults and 65-90% for children of the ingested phosphate, while the rest is excreted in the faeces (Abrahamsson, Andersson et al. 2013). In most foods the bioavailability, the proportion of phosphorus capable of being absorbed is high, yet all plant seeds such as cereals, beans and nuts store phosphorus as phytic acid, which cannot be hydrolysed in the mammalian digestive system. Hence, the main part of the phosphorus in plant seeds is unavailable. However, minor portion of phosphorus can be absorbed if foods contain the enzyme phytase, or due to the fact that some colonic bacteria which are able to degrade phytic acid (Institute of Medicine, 1997). Diets containing high amounts of phytic acid decrease the absorption of phosphorus from other sources to approximately 30%.

The absorption mainly takes place in the upper part of the small intestine by passive diffusion but also in the duodenum via active transport controlled by the active metabolite of vitamin D, 1,25-$(OH)_2D_3$ (calcitriol). The phosphate uptake depends on the vitamin D-status (Abrahamsson et al., 2013). The network is driven by endocrine negative feedback loops between PTH, fibroblast growth factor 23 (FGF-23), vitamin D and membrane proteins called Klotho proteins (Hu et al., 2013). Bone has shown to be a endocrine organ, where osteocytes secrete FGF-23 which regulates phosphate, vitamin D and mineral homeostasis (Quarles, 2008). PTH and FGF-23 reduce renal sodium phosphate cotransporter-2a/c (NaPi-2a/c) activities to increase phosphorus renal excretion. FGF-23 additionally suppress renal expression of 1-α-hydroxylase to reduce production of 1,25-$(OH)_2D_3$ the active metabolite of vitamin D, resulting in reduced NaPi-2b activity and reduced absorption of phosphorus. Figure 2 shows how the pathway for regulation of phosphorus decrease high serum levels of phosphorus by increasing urinary excretion and decreasing intestinal absorption.

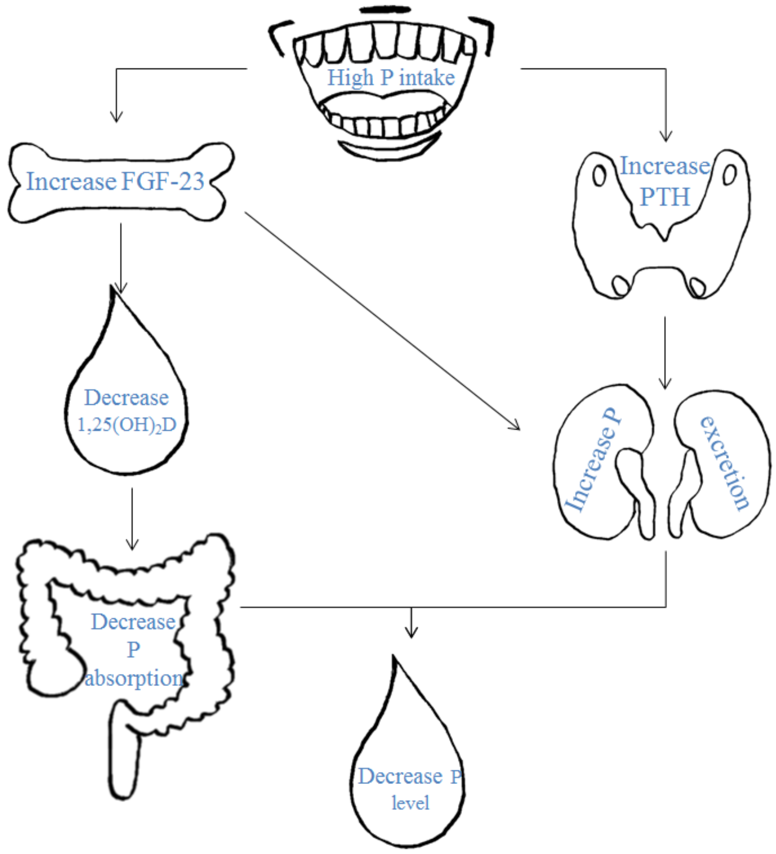

Figure 2. *Regulation of phosphorus. A high phosphorus intake stimulates release of FGF-23 from bone and PTH from parathyroid gland. PTH and FGF-23 reduce renal sodium phosphate cotransporter-2a/c (NaPi-2a/c) activities to increase phosphorus renal excretion. FGF-23 additionally reduces blood concentration of 1,25-$(OH)_2D_3$, resulting in a decreased phosphorus absorption. This leads to a decrease in blood levels of phosphorus. With inspiration from (Lien, 2013).*

1.4 Dietary recommendations

The Institute of Medicine established dietary intake recommendations for phosphorus in 1997 by using serum inorganic phosphate as a biomarker (Calvo & Lamberg-Allardt, 2015; Institute of Medicine, 2006). The European Food Safety Authority (EFSA) regard serum phosphate as an unreliable biomarker for phosphorus status since serum phosphorus concentration is so well regulated. Independent of intake the concentration remains relatively constant due to renal regulation. This makes serum phosphorus an unreliable biomarker for intake of phosphorus. Instead of using serum phosphate data as the Institute of Medicine, EFSA choose another approach to set Dietary Reference Values (DRVs) for phosphorus (Calvo & Lamberg-Allardt, 2015; EFSA, 2015).

1.4.1 EFSA

EFSA consider data to set DRVs for phosphorus insufficient hence Adequate Intake (AI) for different age groups was set (Table 1). AI is the average nutrient level consumed on a daily basis by a typical healthy population that is assumed to be adequate for the population's needs (EFSA, 2017).

Table 1. *Phosphorus intake according to EFSA recommendation*

Phosphorus mg/day		**Adults**	**7-11 months**	**1-3 y**	**4-10 y**	**11-17 y**
Adequate intake	AI	700	200	300	600	800

In 2005, EFSA concluded that it was not possible to establish a Tolerable Upper level (UL) for phosphorus due to lack of clear evidence to base the decision on. UL is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects to almost all individuals in the general population. Adverse effects of excessive phosphorus intake have been reported in animal studies. Examples of effects are hyperparathyroidism, skeletal deformations and bone loss. These effects have only been reported among patients with end stage renal disease and according to EFSA available data is insufficient to establish an UL (EFSA, 2015). An increase in PTH concentration has been showed in acute and short-term loading studies, but no significant changes have been showed in long-term studies with a phosphorus intake up to 3000 mg/day. Neither were any effects on markers of bone remodelling found or evidence that high phosphorus intake impair the effects of secondary hyperparathyroidism induced by an inadequate calcium or vitamin D intake (EFSA, 2015). Symptoms such as osmotic diarrhoea, nausea and vomiting were observed when phosphate supplements were distributed to healthy subjects with a dosage higher than 750 mg/day. These symptoms were not considered suitable as basis to set an UL for phosphorus from diverse sources (EFSA, 2015).

1.4.2 Nordic Nutrition Recommendations

The Nordic Nutrition Recommendations (NNR) (Table 2) on the other hand have stated a provisional UL at 3000 mg/day based on the EFSA evaluation concluding that healthy people can tolerate intakes of up to 3000 mg/day. NNR recommend a phosphorus intake at 600 mg/day for adults. Recommended intake (RI) is defined as the average daily dietary intake level that meets the nutrient requirement for 97-98% of healthy individuals in a group (NNR, 2014).

Table 2. *Phosphorus intake recommended by NNR*

Phosphorus mg/day		**Adults**	**2-5 y**	**6-9 y**	**10-13 y**
Recommended intake	RI	600	470	540	700
Average requirement	AR	450			
Lower intake level	LI	300			
Upper intake level	UL	3000			

1.5 Estimated intake

1.5.1 Total dietary intake

The National Health and Nutrition Education Surveys (NHANES) monitor the intake of essential nutrients in the USA. Surveys have been conducted in 2 year waves since 2000 (Calvo et al., 2014). Data from NHANES have shown that the dietary intake of phosphorus has significantly increased (p=0.0151) with 4.0% between year 2001 and 2014. The estimated dietary phosphorus intake in 2001-2002 was 1345 mg/day and 1399 mg/day in 2013-2014 (McClure et al., 2017). The intake can also be measured as a so called phosphorus density i.e. energy adjusted intake and NHANES showed an intake of 1504 mg/10 MJ during 2009-2010 for the American population. Results from NHANES showed that the dietary phosphorus consumption steadily increase in the U.S and that the intake exceeds the intake guidelines for both men and women (McClure *et al.*, 2017; Calvo & Lamberg-Allardt, 2015).

1.5.2 Intake of inorganic vs. organic phosphorus

The total content of phosphorus in the food as well as the chemical form affects the phosphorus balance. The phosphorus content in the food can be either natural or added, also referred to as organic or inorganic phosphorus. These two types differ in rate and efficiency of absorption. Natural (organic) phosphorus has a slower absorption rate and a lower efficiency since organic phosphorus is dependent on enzymatic digestion to be released from the carbon component. Inorganic phosphorus salts added to food in the form of food additives have a higher absorption rate since no enzymatic digestion are required and the stomach acid easily dissociates the phosphorus (Calvo *et al.*, 2014; Kalantar-Zadeh *et al.*, 2010). Hence, it might be of interest to measure not only the total, but also the amount organic and inorganic phosphorus intake.

1.5.3 Calcium to phosphorus ratio

Another way to evaluate the phosphorus intake is to measure the calcium to phosphorus ratio. Phosphate and calcium form the hard structure of bones. If calcium levels are too low, calcium will be resorbed from the bones. Bone resorption implies a process where small parts of bone are degraded. This involves degradation of both organic matrix and hard mineral. Calcium and phosphate ions and other bone matrix components are then released to the ECV and blood. The resorption process increases with a diet low in calcium and high in phosphate. Therefore, the balance between the two minerals is of interest. A dietary ratio of calcium to phosphorus between 1:1 and 1:2 are considered optimal among adults. With a low intake of dairy products the ratio might be as low as 1:4 (Anderson et al., 2012). EFSA has declared that actual amounts of calcium and phosphorus absorbed from diet are not possible to determine. Hence, they use whole-body molar ratio of calcium to phosphorus ranging from 1.4:1 to 1.9:1 to set DRVs for phosphorus (EFSA, 2015).

1.6 Deficiency

Phosphorus deficiencies are rare among the healthy population due to the high phosphorus content in most foods. Genetic disorders, tumour-related phosphate wasting and abnormal dietary problems such as anorexia and alcoholism may lead to phosphorus deficiency (Calvo & Lamberg-Allardt, 2015). Hypophosphatemia occurs when serum phosphorus concentration decreases below 0.80 mmol/L (2.48 mg/dL) (EFSA, 2015; Gaasbeek & Meinders, 2005). Symptoms associated with hypophosphatemia are muscle weakness, bone pain, rickets and osteomalacia, anaemia and loss of appetite. Depending on growth status the skeleton will exhibit rickets or osteomalacia (EFSA, 2015). Large intakes of especially pharmaceuticals containing aluminium, for example antacid (acid binding) create insoluble salts with phosphate in the intestine. This phosphate is non-available and in combination with a low intake might result in phosphorus deficiency (Abrahamsson et al., 2013).

1.7 Problems associated with excessive phosphorus intake

In the general population, excessive intake of phosphorus is considered as a greater risk than deficiency. Concerns that phosphorus containing food additives increase serum phosphate in the general population to harmful levels have been raised (Stenvinkel et al., 2014). Studies of chronic kidney disease patients have indicated a significant interaction between gradual rise in serum phosphate and cardiovascular disease as well as increased mortality (Slinin *et al.*, 2005; Block *et al.*, 1998). Due to this complication phosphate binding treatment is a standard procedure when treating patients suffering from CKV (KDIGO Kidney Disease Improving Global Outcomes, 2009). The kidneys control the balance between calcium and phosphorus and when the kidney function decreases the capacity of excreting excessive phosphorus is reduced (Kidney Health Australia, 2015). However, there are reasons to suspect that high serum phosphate levels also are associated with CVD among the general population (Foley, 2009). In a healthy population cohort study (2176 men) an increase in serum phosphate within the normal range was proposed to increase the risk of CVD (Larsson et al., 2010). Another cohort study followed people with normal renal function (n= 24184) as well as people with CKD (n=33648) over 2.5 years and found that higher serum phosphate levels correlate with increased risk for CVD both for people with and without CKD (McGovern et al., 2013). Vascular calcification has been suggested as potential mechanism behind this (Lau et al., 2011). A retrospective longitudinal cohort study with 94 989 subjects showed that elevated serum phosphate concentrations are associated with an increased risk for end-stage CKD and mortality (Sim et al., 2013). The explanation suggested is to be cell damage caused by phosphorus and calcium crystals (Aihara et al., 2003).

NHANES 1989-1994 showed that a phosphorus intake above 1400 mg/day is associated with a two-fold (p=0.03) all-cause mortality risk. Below the 1400 mg/day threshold no significant relationship was observed. In NHANES phosphorus intake is based on one 24-h dietary recall interview (Chang et al., 2014). An increase in blood phosphate levels usually reduce serum levels of calcium by creating calcium-phosphate complex, which in turn stimulates a release of PTH as an attempt to re-establish calcium balance (Razzaque, 2011). Stimulation of PTH secretion suppresses $1,25(OH)_2D_3$ as well as intestinal calcium absorption. A diet with low calcium to phosphorus ratio might have a more adverse effect on bone metabolism in healthy adults than the phosphorus level alone, but this has not been fully demonstrated yet. However, there are reason to monitor the ratio between calcium and phosphorus as well rather than just the specific phosphorus concentration (Dawson-Hughes, 2006). Osteoporosis is a serious problem predominately among elderly women. The risk is dependent both on current rate of bone loss and peak bone mass. Therefore it is of great interest to enhance peak bone mass among young women (Calvo, 1994).

1.8 Phosphorus containing additives

Phosphorus is not included in the mandatory nutrient labelling information. The requirements only cover one mineral: sodium. Producers are generally allowed to include the mineral content if products contain more than 15% of the reference intake. In the case of phosphorus the reference intake is set to 700 mg/day and products containing more than 105 mg of phosphorus per 100g of food would be allowed to label the phosphorus content (EU regulation 1169/2011). The phosphorus containing additives on the other hand must be declared in the ingredients list and consumers therefore have a possibility to exclude products with added phosphorus but they are unable to quantify the consumed amount phosphorus (Calvo et al., 2014). Food industry uses additives containing phosphorus to improve texture, colour and taste (Calvo *et al.*, 2014; Calvo & Uribarri, 2013). Table 3 shows commonly used phosphorus containing additives.

Table 3. *Phosphorous containing additive (EU regulation 1333/2008). Most additives have a wide range of applications. E1410-1442 are modified starches containing phosphorus*

E-number	Name	Type	Usage
E338	Phosphoric acid	Antioxidant	
E339	Sodium phosphates		
E340	Potassium phosphates		
E341	Calcium phosphates		
E343	Magnesium phosphates		
E442	Ammonium phosphatides	Emulsifying, stabilizing, thickening and gelling	Chocolate products
E450	Diphosphates	Emulsifying, stabilizing, thickening and gelling	
E451	Triphosphates		
E452	Polyphosphates		
E541	Sodium aluminium phosphate acidic	Other additives	Fine bakery as sponge cake
E1410	Monostarch phosphates	Modified starches: Emulsifying, stabilizing, thickening and gelling	
E1412	Distarch phosphate		
E1413	Phosphated distarch phosphate		
E1414	Acetylated distarch phosphate		
E1442	Hydroxy propyl distarch phosphate		

Phosphates increase the water holding capacity of raw and cooked meat and are for example used in sausage production, when curing ham and also to prevent drip loss from poultry and seafood (Lindsay, 1996). Polyphosphates such as tetrasodium diphosphate are often added to meat products such as cured ham to increase their water holding capacity. Tetrasodium diphosphate is manufactured by heating orthophosphates. The most frequently used have two or three phosphorus atoms per molecule. The advantages are several, above all for the producers to improve the yield. An enhanced retention of muscle water and its solutes during cooking improve juiciness and flavour of products such as bacon and ham, which is sought after by consumers. Another advantage of polyphosphates is that they appear to delay onset of rancidity (Coultate & Blumenthal, 2008). Phosphate additives have various other functions including acidification, buffering, anticaking, leavening, stabilizing emulsifying, and to prevent autoxidation. Sodium tripolyphosphate improves moisture retention in cured meat and is used as an emulsification aid in minced meats and when producing cheeses. Phosphoric acid (H_3PO_4) acidifies soft drinks and also brings a preservative function. Calcium hydrogen phosphate $Ca(HPO_4)_2$ is used as a leavening acid and anticaking agent in powders. Also modified starch (E1404-1452) in some cases contains phosphorus (E1410, 1412-1414, 1442). Since most producers only state ‘modified starch’ on the label it is difficult to estimate to which extent phosphorus containing modified starch is used.

Phosphates carry negative charges at the pH of most foods and polyphosphates act as polyelectrolytes. These negative charges generate a strong Lewis-base character to phosphates and a strong tendency to bind metal cations. In this way polyphosphates act as chelating agents that bind ions such as iron and copper to reduce the rate of autoxidation of meat lipids. This ability to bind metal ions may be the reason behind the properties associated with phosphates as an food additive (Lindsay, 1996). Polyphosphates are added at levels around 0.1-0.3% (Coultate & Blumenthal, 2008).The use of phosphorus containing additives continue to increase in the USA as food manufacturers finds new areas of use (Calvo et al., 2014). The growing use of phosphate additives is recognized in the work with updating the nutrient databases as foods are reanalysed. In particular, fast food is a contributor to the increased phosphorus intake in the USA. A number of studies comparing direct chemical analyses of phosphorus content with estimations from nutrient databases have showed significant underestimations when using the values from databases (Calvo et al., 2014). A review of chicken products purchased in Cleveland, USA report that 92% of the analyses products contained phosphorus containing additives. Additives containing phosphorus significantly increase the amount of phosphorus in chicken products. The survey showed that for all products with phosphorus containing additives were the actual phosphorus content higher than the content expected from nutrient databases (Sullivan et al., 2007). However, the same tendency has not been observed in Swedish products. National Food Agency (NFA) compared different meat and processed meat products in 2015. Fresh chicken had higher phosphorus content than frozen. But the explanation is not a difference in additives but rather a dilution effect. The frozen ones are injected with brine solution. The frozen chicken contained about 15% water and salt. No major differences between sausages of different quality were noticed, but slightly higher phosphorus content can be seen in sausage with high meat content (The National Food Agency food database, 2017). An American comparison between food with and without additives show that a four day menu based on more processed food compared to a low-additive menu resulted in a 60% increase ($p < 0.001$) in total phosphorus content (Carrigan *et al.*, 2014)

1.9 Carbonated soft drinks

Phosphoric acid is one of the phosphorus containing additives consumed in the highest amounts and has a high absorption rate and bioavailability (100%). Phosphoric acid (E338) is added to cola-flavoured soft drinks to achieve the sour taste, most other soft drink flavours contain citric acid instead. Since carbonated soft drinks flavoured with cola are consumed in large amounts all over the world, often also without simultaneously food intake, this increases the risk for periodic repetitive peaks in serum phosphate (Calvo et al., 2014). The consumption of soft drinks in absence of food decreases the calcium to phosphorus ratio which might be problematic. A significant increase in serum phosphate ($p < 0.001$) was reported from a randomized crossover design where 2.5 L of cola or 2.5 L of skimmed milk was consumed for 10 consecutive days with 10 days washout in between. The subjects consumed a low-calcium basic diet during the trial. Also $1,25(OH)_2D_3$ ($p < 0.001$), PTH ($p=0.046$) and osteocalcin ($p < 0.001$) significantly increased during the cola period compared to the milk period. The bone resorption increased during the cola period and this indicated that high cola consumption can have negative effects on bone health among individuals with a low calcium intake. The replacement of milk with cola results in a lower calcium to phosphorus ratio (Kristensen et al., 2005). A strong association has been shown between cola intake and bone fractures among girls and a high intake of dietary calcium was shown to have a protective effect (Wyshak & Frisch, 1994).

2 Aim

The aim of this thesis was to estimate if the phosphorus intake in the Swedish population has increased during the last 16 years, in a similar way as in the USA. It was also estimated if there was a certain food category responsible for the variations in dietary phosphorus intake. The intake of inorganic phosphorus and the ratio between calcium and phosphorus were estimated to evaluate whether these measures can be used to complement total phosphorus intake when evaluating excessive intake.

3 Method

3.1 Market Basket

The Market Basket (MB) is a project conducted by the NFA aiming to obtain exposure data for nutrients and toxic compounds. The Market Basket project has been conducted using a similar protocol four times since 1999 and the results enable a systematic overview of average dietary intake for the Swedish population and investigations of time trends. The market basket study also enables to identify food categories that are the major contributors to the total intake of for example phosphorus. The Swedish Board of Agriculture regularly provides regularly information on annual availability of foodstuffs on the Swedish market and the per capita consumption. The intake is estimated from food production and trade statistic and is presented as intake per capita (National Food Agency, 2017b).

3.1.1 Food items

Food items representing the population intake were purchased and analysed. The food items were divided in 12 main food categories and a shopping list has been determined for each survey to enable purchase of food items corresponding to their market share. The food categories and some examples of food items belonging to the specific groups can be seen in Table 4. The shopping list aims to cover about 90% of the total annual consumption.

Table 4. *Food categories according to Market Basket 2015 and some examples from each group*

Category number	**Food category**	**Examples**
1	Cereals	Flour, bread, pasta
2	Pastries	Cakes, biscuits, buns, pirogue, pizza
3	Meat	Meat products, cured/processed meat
4	Fish	Fresh and frozen, canned
5	Dairy products	Milk, cheese, yoghurt
6	Eggs	Fresh egg
7	Fats and oils	Butter, mayonnaise, cooking oil
8	Vegetables	Fresh and frozen, canned
9	Fruits	Fresh and frozen, canned, juice
10	Potatoes	Fresh, French fries, crisps
11	Sugar and sweets	Sugar, ice-cream, candy, ketchup
12	Beverages	Soft drinks, beer (up to 3.5 vol.% alcohol), mineral water

3.1.2 Samples

During the four sample periods, i.e. year 1999, 2005, 2010 and 2015, different minerals have been in focus and phosphorus has not been analysed within this project until 2015. Samples from year 1999, 2005 and 2010 were re-analysed in July 2017 to assess phosphorus content. The annual per capita consumption can be seen in Table 5 as well as the change between year 1999 and 2015. Samples corresponding 1% of the total annual consumption of each food item were analysed. The samples from 2015 were analysed according to the initial sample plan in November 2015.

Table 5. *Consumption per capita 1999-2015. The weights represent the annual per capita consumption for each Market basket (MB) study. Change indicate increase/decrease between 2005-2015*

Group	**Category**	**Annual per capita consumption (kg)**				**Change (%)**
		MB 1999	**MB 2005**	**MB 2010**	**MB 2015**	**2005-2015**
1	Cereals	69.4	91.1	84.4	83.6	-8
2	Pastries	13.7	19.1	18.5	17.7	-7
3	Meat	56.7	70.8	75.9	75.9	7
4	Fish	13.3	17.2	18.5	16.0	-7
5	Dairy products	168.5	175.8	155.7	147.0	-16
6	Eggs	9.2	8.1	8.4	10.1	25
7	Fats and oils	17.5	14.4	14.5	16.5	15
8	Vegetables	54.8	63.6	70.4	70.6	11
9	Fruits	64.1	68.3	86.7	88.9	30
10	Potatoes	51.4	44.3	45.8	46.1	4
11	Sugar and sweets	35.3	37.8	45.3	45.9	21
12	Beverages	118.8	126.7	120.5	115.0	-9
	Total	**672.7**	**737.2**	**744.6**	**733.3**	**-1**

The samples for 1999 and 2010 were pooled. Samples from 2005 were purchased in four different Swedish cities: Göteborg, Malmö, Uppsala and Sundsvall. In each city food items were collected from two different food chains. In 2015, all purchases were made in the Uppsala area from five different food chains. Main statistical comparisons were made between year 2005 and 2015. The average daily intakes of phosphorus were calculated by multiplying the concentration obtained with laboratory analysis for each food category by the amount of food representing daily per capita consumption.

3.1.3 Chemical analysis

The analysis of total phosphorus concentrations in November 2015 and July 2017 were performed by High Resolution Inductively Coupled Plasma Mass Spectrometry (HR-ICP-MS) by ALS Scandinavia AB, Luleå (Engström et al., 2004). The analysis of phosphorus content had a coefficient of variation (CV %) of 7.5%, limit of detection (LOD) of 0.059 mg/100g and limit of quantification (LOQ) of 0.196 mg/100g.

3.1.4 Quality control

Since phosphorus has not been analysed during previous Market basket studies, a quality control was established to assess the reliability of the re-analysed values. The original values for minerals such as calcium, iron, potassium, magnesium and zinc were compared with the re-analysed values. The logarithmic quota between the re-analysed and the original value were statistically evaluated. Food categories with phosphorus concentrations below LOQ were excluded from statistical evaluation.

3.1.5 Statistical analyses

Differences in concentration and intake from different food categories between sample years 2005 and 2015 were investigated with single ANOVA as well as differences in total intake between 2005 and 2015. The quality control for the minerals was analysed using a Wilcoxon Signed Rank Test. A p-value <0.05 was considered statistically significant. The statistical analyses were conducted with Minitab version 15 (Coventry, UK).

3.1.6 Estimation of phosphorus intake from additives

To estimate intake of inorganic phosphorus a compilation starting from the shopping list established for Market basket 2015 were made. The maximum levels of phosphorus containing additives allowed according to EU regulation 1333/2008 were summarised. The phosphorus containing additives included in the summary were; phosphoric acid, sodium phosphate, potassium phosphates, calcium phosphates, magnesium phosphates, ammonium phosphatides, diphosphates, triphosphates and polyphosphates. Since only a few of all approved modified starches contain phosphorus, modified starch was excluded from the summary.

3.1.7 Estimation of organic phosphorus

The shopping list for 2015 was utilized to identify products on the Swedish market that containing additives with phosphorus. This information together with EU regulation 1333/2008 was useful when estimating the intake of inorganic phosphorus. Some food categories as vegetables, fruit, cereals and meat excluded processed meat are assumed to contain no phosphorus containing additives. Summarizing the phosphorus content from these food categories provided information on the organic phosphorus intake. Also, other food categories contain organic phosphorus but to which extent is unknown.

3.2 The national food consumption survey ‘Riksmaten’

The result from the Market Basket project was also compared to the result from the last two ‘Riksmaten’ studies, conducted in 2010-2011 and 1997-1998. ‘Riksmaten’ is a national dietary study, which monitors the intake of foods and nutrients in the Swedish population.

3.2.1 ‘Riksmaten adults’

The latest ‘Riksmaten adult’ survey was carried out between May 2010 and July 2011 and the study population took part of a dietary survey and completed a dietary questionnaire. The diet record continued for four continuous days and the participants were able to use a list with over 1900 food items and dishes to register their dietary intake. The national food composition database at the NFA was used to estimate the nutrient values. The phosphorus intake was calculated both as absolute intake per day (mg/day) and as energy adjusted intake (mg/10MJ) (Amcoff et al., 2012).

3.2.2 ‘Riksmaten adolescents’

‘Riksmaten adolescents’ is a national survey that investigates the food intake among adolescents during 2016-2017. In total 3099 adolescents in the age of 11, 14 and 17 years have participated in 2 × 24 h recall using web registration (National Food Agency, 2017a). ‘Riksmaten adult’ survey in 2010 showed the highest intake of carbonated sodas in the youngest age range (18-30 years) (Amcoff et al., 2012). Therefore, there were reasons to suspect that the intake could be higher among adolescents, especially of 17 year olds. In the ‘Riksmaten adolescents’ study information about consumption of soft drink flavoured with cola was collected. From this information, high consumers can be detected and the intake of phosphorus from exclusively cola-flavoured soft drinks can be estimated in this group. Phosphoric acid is added to cola-flavoured soft drinks to achieve the sour taste, other soft drinks contains citric acid instead.

4 Results

4.1 Time trends in estimated phosphorus intake

The total diet intake of phosphorus did not differ between 1999 and 2015. The daily intake per capita continuously lay approximately at 2000 mg/day (Table 6). The main statistical comparison was made between 2005 and 2015 (Table 7) and a statistically significant (p=0.006) decrease was observed.

Table 6. *Mean value and standard deviation (SD) of total phosphorus intake (mg/person/day)*

	n[1]	**Total (mg/person/day)**
Market Basket 1999	1	1868
Market Basket 2005	8	2024 (±48)
Market Basket 2010	1	2070
Market Basket 2015	5	1821 (±60)

n[1] number of samples

Table 7. *Phosphorus intake for each sample (city/store) 2005 and 2015*

2005	**Intake[1] (mg/person/day)**	**2015**	**Intake (mg/person/day)**
Göteborg store chain 1	2112	Store chain 1	1835
Göteborg store chain 2	1923	Store chain 2	1964
Malmö store chain 1	1980	Store chain 3	1786
Malmö store chain 2	1882	Store chain 4	1876
Uppsala store chain 1	2112	Store chain 5	1642
Uppsala store chain 2	1981		
Sundsvall store chain 1	2133		
Sundsvall store chain 2	2068		
Mean (SD)	**2024 (±48)**		**1821 (±60)**

[1]Mean value for fat (=5.22mg) was used in each market basket from 2005 since food category 'fat' was analysed as a pooled sample

‘Riksmaten adults’ studies also indicated that the phosphorus intake in Sweden has not increased. Table 8 shows the mean phosphorus intake as well as the 5th and 95th percentile. The intake of phosphorus is about 300 mg higher among men than women. Men with the highest intake (95 percentile) have a daily intake of phosphorus over 2300 mg/day according to ‘Riksmaten’ 2010-2011.

Table 8. *Mean (P5, P95) phosphorus intake in ‘Riksmaten adults’ 1997-1998 and 2010-2011*

	n	**Mean intake (P5, P95) (mg/person/day)**		
		Men	**Women**	**Total**
‘Riksmaten’ 1997-1998	1215	1574 (932, 2381)	1291 (783, 1855)	1428 (n.d)
‘Riksmaten’ 2010-2011	1797	1541 (876, 2330)	1242 (702, 1811)	1374 (778, 2133)

n.d no data, P5 indicates 5th percentile and P95 95th percentile

4.1.1 Calcium to phosphorus ratio

The calcium to phosphorus ratio seems to be rather stable between 1999 and 2015, as can be seen in Table 9. According to ‘Riksmaten’ surveys the ratio has been stable between the two studied periods.

Table 9. *Ratio between calcium and phosphorus intake (molar relationship)*

Market Basket		**‘Riksmaten’**	
1999	1:1.9	1997-1998	1:1.9
2005	1:2.1		
2010	1:2.2	2010-2011	1:2.0
2015	1:2.1		

4.1.2 Estimation of inorganic and organic phosphorus

If all producers added maximum permitted level of phosphorus in their products, this would result in an intake of about 2364 mg inorganic phosphorus per day based on Market basket 2015. There is no reason to believe that this is the case. An estimation of organic phosphorus share showed that at least 78% of the phosphorus intake is organic. Some food categories such as vegetables, fruit, cereals, dairy and meat (excluding processed meat) are assumed to contain no phosphorus containing additives. For Market basket 2015 these categories contributed with 1422 mg/day, i.e. 78% of the phosphorus intake and this is considered to be the minimum organic phosphorus intake.

4.1.3 Energy corrected intake

In 2010, the intake of phosphorus expressed as a proportion of phosphorus to the total energy intake based on 'Riksmaten' survey, was determined as 1671 mg/10MJ for men, 1697 mg/10MJ for women and 1685 mg/10MJ in total. Based on Market basket 2010 the energy corrected intake for men and women was 1656 mg/10MJ.

4.2 Time trend of phosphorus concentrations in market baskets

The concentration of phosphorus has significantly decreased between 2005 and 2015 in the food groups; egg, sugar, potato and vegetable (Table 10). A significant increase in phosphorus concentration can be seen only in the food group fruits. Phosphorus concentration in eggs decreased with nearly 20% between year 2005 and 2015.

Table 10. *Phosphorus concentrations in different food categories for each market basket and the change between 2005 and 2015. * indicates a significant difference*

Category	**Concentration (mg/100g)**				**Change %** (2005-2015)
	1999	**2005 (SD)**	**2010**	**2015 (SD)**	
	(n=1)	(n=8)	(n=1)	(n=5)	
Eggs	302	239 (±24)	342	197 (±7)	-18*
Fish	191	175 (±18)	183	162 (±10)	-7
Cereals	175	177 (±18)	185	164 (±19)	-7
Meat	202	162 (±21)	195	180 (±28)	11
Dairy products	166	153 (±15)	158	142 (±7)	-7
Pastries	143	130 (±27)	154	133 (±14)	3
Sugar and sweets	78	88 (±13)	82	71 (±11)	-20*
Potatoes	42	64 (±7)	54	51 (±5)	-21*
Vegetables	33	37 (±4)	33	29 (±2)	-21*
Fruits	25	24 (±1)	24	27 (±2)	9*
Beverages	9	12 (±6)	7	7 (±1)	-41
Fats and oils	29	13 (±1)	12	12 (±3)	-12

4.3 Main phosphorus sources

The estimated phosphorus intake from the food categories meat and fruit has significantly increased, whereas the estimated intake of phosphorus has significantly decreased from three food groups: dairy products, cereals and potato. The dietary phosphorous intake from each category can be seen in Table 11.

Table 11. *Phosphorus intake mg/person/day from each category and change between 2005 and 2015. * indicates a significant difference*

Category	**Intake (mg/person/day)**				**Change %** (2005-2015)
	1999 (n=1)	**2005 (SD)** (n=8)	**2010** (n=1)	**2015 (SD)** (n=5)	
Dairy products	768	737 (±74)	673	570 (±27)	-23*
Cereals	332	442 (±45)	429	376 (±44)	-15*
Meat	314	314 (±41)	405	381 (±60)	21*
Sugar and sweets	61	92 (±14)	102	89 (±13)	-3
Fish	70	82 (±8)	93	74 (±4)	-10
Potatoes	59	78 (±9)	68	65 (±6)	-18*
Pastries	54	68 (±14)	78	64 (±7)	-6
Vegetables	50	64 (±7)	61	58 (±4)	-10
Eggs	76	53 (±5)	79	55 (±2)	2
Fruits	43	46 (±2)	57	62 (±4)	36*
Beverages	28	40 (±19)	22	21 (±4)	-47
Fats and oils	14	5 (±0)	5	5 (±1)	-4
Total	**1868**	**2020** (±48)	**2070**	**1820 (**±60)	**-10**

Main contributor to the dietary phosphorus intake is dairy products (Table 12). The contribution of phosphorus from dairy products decreased. In 1999 accounted dairy products for 41% of the phosphorus intake, and in 2015 32%. The second largest dietary phosphorus sources after dairy products were cereals and meat. The contribution from cereals has been stable around 20% and the contribution from meat has increased throughout the years. The intake of phosphorus from meat has increased from 17 to 21% and in 2015 meat contributed with as much phosphorus as cereals (21%).

Table 12. *The percentage share of dietary phosphorus intake*

Category	Phosphorus intake from each category (%)			
	1999	**2005**	**2010**	**2015**
Dairy products	41	36	33	32
Cereals	18	22	21	21
Meat	17	16	20	21
Fish	4	4	4	4
Eggs	4	3	4	3
Sugar and sweets	3	5	5	5
Potatoes	3	4	3	4
Pastries	3	4	4	4
Vegetables	3	3	3	3
Fruits	2	2	3	3
Beverages	2	2	1	1
Fats and oils	1	0	0	0

4.3.1 Processed meat

In 2015, processed meat represented 27% of the total meat intake. The total intake of meat has increased during the time period, however the intake of processed meat has not followed the same trend and the proportion of processed meat has therefore decreased since 1999 as can be seen in Table 13.

Table 13. *Amount of consumed meat (total) and processed meat for each Market basket (MB) study 1999 to 2015*

	MB 1999	**MB 2005**	**MB 2010**	**MB 2015**
Meat, total (g)	568	685	759	774
Meat, processed (g)	209	229	245	207
Processed meat (%)	37	33	32	27

4.3.2 Cola-flavoured soft drink intake

In the survey ‘Riksmaten adolescents’ data on soft drink consumption in adolescents was collected. Adolescents with the highest intake (95th and 99th percentile) consumed 465 ml/day (95th percentile) and 1015 ml/day (99th percentile) cola-flavoured soft drink respectively (Table 14). The 17 year olds have an even higher intake and consume 1200 (95th percentile) and 2000 (99th percentile) ml/day. This corresponds to a phosphorus intake of about 178-296 mg/day, exclusively from soft drinks with cola-flavour.

Table 14. *Intake of soft drinks with cola-flavour (regular and light) 95 and 99 percentile*

	n	Soft drink with cola- flavour (ml/day)	Phosphors intake from soft drinks (mg/day)
'Riksmaten adolescents'	3099	465, 1015	69, 150
17 year olds	996	1200, 2000	178, 296

Cola drinks contains in average 14.8 mg/100g phosphorus (The National Food Agency food database, 2017)

4.4 Quality control of mineral analysis

The quality control summarized in Table 15 showed several significant differences between the original analysis and the re-analysis. A positive logarithmic quota means that re-analysed value is higher than original value. The coefficient of variation (CV %) applies to the re-analysed values.

Table 15. *Quality control to compare original with re-analysed phosphorus content. * indicates a significant difference*

Mineral	Year	n samples	CV %	Quota (log)	p-value
Ca	1999	12	5.2	0.05182	0.005*
Fe	1999	10	1.8	-0.001	0.919
K	1999	12	7.7	0.1271	0.003*
Mg	1999	12	4.8	0.07209	0.009*
Na	1999	12	7.3	0.05125	0.017*
Na	2005	12	7.3	0.03388	0.031*
Fe	2010	12	1.8	0.01432	0.556
Na	2010	12	7.3	0.06589	0.013*
Zn	2010	12	3.5	0.04318	0.038*

5 Discussion

5.1 Time trends in estimated phosphorus intake

Contrary to the results from NHANES (McClure *et al.*, 2017) the estimated total dietary intake of phosphorus in Sweden has not increased since year 1999. In contrast a statistically significant decrease was found in the total dietary intake of phosphorus between 2005 and 2015. The dietary phosphorus intake has continuously been below or barely above 2000 mg/person/day. The situation in Sweden, therefore, is different from USA, were concerns have been raised. However, the intake in Sweden is still about three times higher than RI and AI at 600 and 700 mg/day for adults, respectively. These results are considered to be acceptable and further actions to decrease the phosphorus intake among the Swedish population are not considered to be necessary at the moment. Since consequences of excessive phosphorus intake are potentially serious, it is important to continuously monitor the intake of phosphorus in further Market Basked studies.

This study has several limitations, e.g. due to the method set up, no statistical comparisons can be made between total intake for 1999 and 2015. In 1999 and 2010 only one pooled sample was analysed. However, the results from 1999 and 2010 are still interesting since they indicate a stable intake of phosphorus. In 2005 eight samples (four cities) and in 2015 five samples (five stores) were analysed. Despite this, it is obvious that no increasing trend can be interpreted. In addition, the national food consumption surveys ‘Riksmaten’ indicated a rather stable phosphorus intake. Men have a higher total intake of food and as a consequence also a higher phosphorus intake (300 mg higher intake per day) than women. According to ‘Riksmaten’ 2010-2011 men have a lower energy adjusted intake of phosphorus intake than women. Men have a daily intake at 1671 mg/10MJ and women 1697 mg/10MJ and a difference in consumptions pattern that explains the difference can therefore not be suspected. The adjusted phosphorus intake in 2009-2010 presented by NHANES for men and women was 1585 mg/10MJ. This indicates that the phosphorus intake may be higher in Sweden compared to USA. Both 'Riksmaten' and NHANES are food consumption surveys and are assumed to have similar sources of errors. In 'Riksmaten adults' 2010-2011, 5% of the Swedish men had an intake above 2300 mg of phosphorus per day. The intake is well below the UL declared by NNR (3000 mg/day) but since the UL are debatable it is of importance to monitor the trends. Furthermore, NHANES 1988-1994 showed an association between phosphorus intake exceeding 1400 mg/day and all-cause mortality (Chang *et al.*, 2014). Even if the study is based on just one 24-h total diet recall interview there are reasons to take it into account and to be aware, that the general intake in Sweden exceeds this level of phosphorus intake.

5.1.1 Calcium to phosphorus ratio

The calcium to phosphate ratio seems to be rather stable in the Swedish population. Market basket 2015 indicated that the calcium to phosphorus ratio lays around 1:2.1. Results from the national food consumption studies 'Riksmaten adults' confirm these findings. EFSA has not set an actual AR or Population Reference Intake since they consider the data to be insufficient however based the AI on the whole-body calcium to phosphorus ratio which are estimated to range between 1.4:1 – 1.9:1. EFSA use whole-body molar ratio of calcium to phosphorus at 1.4:1 to set DRVs for phosphorus. A molar calcium to phosphorus ratio (1 mmol calcium = 40.1 mg, 1 mmol phosphorus = 30.9 mg) at 1.4:1 (EFSA, 2015) based on calcium intake from Market basket 2015 would imply a recommended intake of phosphorus at 620 mg. In contrast, NNR has based their recommendation on an equimolar relationship (1:1) between calcium and phosphorus (NNR, 2014). Based on the calcium intake from Market basket 2015 would this imply a recommended phosphorus intake of 870 mg. Both these hypothetical recommendations are substantially lower than the estimated intake in Sweden (1820 mg). An imbalance in calcium to phosphorus ratio might have severe effects on health since high serum phosphorus concentrations might increase bone resorption. A cross-sectional study with 147 healthy women showed that an increase of calcium intake to compensate for a high phosphorus intake does not appear to completely correct the imbalance in calcium metabolism even if the calcium to phosphorus ratio is improved. Increasing calcium intake well beyond the nutritional recommendation might lead to other health risks and is therefore not recommended (Kemi et al., 2010).

5.1.2 Intake of inorganic vs organic phosphorus

The intake of inorganic phosphorus is difficult to measure. An attempt to estimate the intake of inorganic phosphorus was made since inorganic phosphorus has a higher resorption rate. This would mean that not only the total phosphorus intake but also the proportion of inorganic phosphorus are of interest when evaluating the phosphorus intake. It is obvious that producers do not add as much phosphorus containing additives as they are allowed to, since the estimated inorganic phosphorus intake based on the regulated levels (2364 mg/day) are well above the estimated total phosphorus intake in the population (1821 mg/day). The estimated minimum organic phosphorus intake at 78% was based on that the food categories; fruit, vegetable, cereals, dairy products and meat (excluded processed meat) are free from phosphorus containing additives. This would imply a maximum intake of inorganic phosphorus at 400 mg/day. Obviously, other food categories also contain organic phosphorus. Cereal and dairy products might as well contain modified starch with phosphorus, but as discussed above it is difficult to deduce that from food labels. Hence, this is a rough estimation and most likely an overestimation of the intake of inorganic phosphorus.

5.2 Time trends in phosphorus concentrations in Market Baskets

In most food categories phosphorus concentrations decreased between 2005 and 2015. There were no significant changes in the food categories were phosphorus containing additives can be suspected as explanation for the increase or decrease in phosphorus content. Phosphorus containing additives are particularly used in processed meat, cola-flavoured soft drinks and as leavening agent in soda breads. No significant changes were seen in the meat, beverages or cereal categories. The concentration is a measure more dependent on the producer rather than the consumer even though purchases are based on market shares. Total intake is on the other hand affected by dietary patterns to a greater extent.

The significant decreases in phosphorus concentrations in eggs, sugar, potato and vegetable and the significant increase in the food category fruits derives from natural phosphorus and is therefore not interesting out of an additive perspective. Furthermore, initial concentration of phosphorus in sugar, potato, vegetable and fruits are low and although changes are statistically significant they are not nutritionally relevant. The meat industry association have been contacted[1] and their opinion is

1. Mail conversation with Managing Director at 'Kött och Charkföretagen' 2017-12-11

that usage of phosphates has decreased in meat products such as ham and sausages over the recent years. This as a consequence of the public debate going on about additives. The consulted version of EU regulation 1333/2008 from 2015 also clarified that usage of phosphate is forbidden in for example raw hamburgers, which contributes to the decreased usage. The effect of this actions cannot be seen as significant differences between different Market basket studies yet, but if this trend is consistent, the effect might be seen in future comparisons.

5.2.1 Egg

Regarding the samples corresponding to egg, there is reason to suspect something is wrong with the samples. In 2005 both the individual samples and the pooled samples containing egg from every sampling location were analyzed and the results differed substantially. A mean value of the phosphorus concentration from all sampling locations was 239 mg/100g while the pooled sample concentration was determined at 338 mg/100g. Therefore, there is reason to suspect that also the pooled samples from 1999 and 2010 at 302 mg/100g and 342 mg/100g, respectively were incorrect. Even though a significant decrease could be identified in phosphorus concentration between 2005 and 2015 this decrease might be explained by alterations in feed given to the egg laying hens. According to the production manager at Lantmännen the feed for egg laying hens was changed around 2010. Instead of adding monocalcium phosphate the enzyme phytase is added to the feed[2]. This might affect the content of phosphors in egg, but how and to which extent is presently unknown.

5.3 Main phosphorus sources

Since 2005 the intake of dairy products has decreased by 16%. Dairy products are the main contributors to phosphorus intake and a decrease in intake from this group could result in a decreased total phosphorus intake. The concentration of phosphorus in dairy products is rather constant but the phosphorus intake decreases due to the decreased total intake of dairy products. The significant changes in phosphorus intake from fruit and potato derive from natural phosphorus and are therefore not interesting out of an additive perspective. The significant decrease from cereals and dairy products may be explained by a decrease both in concentration and total intake of food from those categories. The total intake of meat increase and even though the concentration of phosphorus in the food category meat has decreased substantially, have the intake of phosphorus from meat significantly increased.

2. Mail conversation with Production manager Pullfor, Lantmännen 2017-10-05.

‘Riksmaten adult’ 1997-1998 as well as 2010-2011 also showed that dairy products followed by cereals and meat are the main contributors to the phosphorus intake. The main contributor in America shown in NHANES 2011-2012 were dairy products followed by breads and sweet bakery products (Moshfegh *et al.*, 2016).

5.3.1 Processed meat

Meat consumption has increased with 7% between 2005 and 2015. Since phosphorus containing additives are used in food processing of meat products to increase the water holding capacity it is of interest to estimate the intake of processed meat. Since the intake of processed meat has been rather stable during the 16 years, meanwhile the total intake of meat has increased, the proportion of processed meat has decreased and also the percentage of the annual consumption. The samples from 2015 contained less processed meat products then market basket sampled in 2005, hence a decrease in phosphorus concentration from meat products can be seen. However, as total meat consumption increases the intake of phosphorus from category meat has significantly (p=0.049) increased with 21%.

5.3.2 Cola-flavored soft drink intake

The national food consumption survey ‘Riksmaten adolescents’ was used to estimate the consumption of cola-flavoured soft drinks in the 95th and 99th percentile among Swedish adolescents. These are considered to be high consumers and 1% of the 17 year olds consume 2000 ml cola-flavoured soft drinks per day. These adolescents have an additional intake of phosphorous of 296 mg/day. Based on the mean intake of phosphorus among adults in 2015 (1821 mg/person/day), this would correspond to 16% of the daily phosphorus intake.

The decrease (-47%) in intake of phosphorus between 2005 and 2010 from the food category beverages may be due to purchase of different carbonated drinks. A dilution effect might also have appeared when more mineral water is included. In 2005, 5% of the sampled beverages were composed of miner water and in 2015 there were 9%.

5.4 Quality control

The re-analysed values differed significantly from the original values for several minerals. Minerals as calcium, iron, potassium, magnesium and zinc are comparable with phosphorus based on content levels. Out of these minerals a significant change could be seen for calcium, magnesium, potassium, sodium from 1999, sodium from 2015 and sodium and zinc from 2015. Where a significant difference is seen, the re-analysed value is higher than the original value. If the same trend is expected with phosphorus the concentration of phosphorus for 1999, 2005 and 2010 would be lower than earlier presented. That supports the conclusion that no increase in phosphorus intake has occurred between 1999 and 2015. One explanation might be that freezing and thawing of samples has caused loss of water and thereby a concentration. The same concentration effect can be seen for all stored samples. The CV is rather low for the analytical method used for re-analysis of minerals, which indicates that the method is suitable for the purpose. Method development has occurred between 1999 and 2017 which might explain some of the differences between the original analysis and the re-analysed value. For sodium have a swift in method taken place. Before was a spectrophotometric method and now ICP-MS.

5.5 Sample treatment

The samples have been thawed several times since 1999 for different analyses. If there is a freeze dry effect, original values for 1999 would be lower (less concentrated) than the re-analysed values from 2017. The previous studies have indicated problems with creating homogenous samples especially for dairy samples which include both liquid products as milk and solid such as cheese. In 2015 dairy products were for the first time divided into two groups, solids and fluids due to problems with homogenization (National Food Agency, 2017b). It is difficult to determine the effect of the previous procedure, but since the concentration in dairy products has decreased between 2005 and 2015 with 7.4% the change in method is not assumed to have a large impact on the result for minerals. The phosphorus concentration is higher in the solid more concentrated part of the dairy products than the liquid.

5.6 Market Basket vs. ‘Riksmaten’

The Market Basket has an advantage over ‘Riksmaten’ survey, since it can generate large amounts of data in a cost-effective way. The Market basket studies perceive fast changes in food composition and also cover compounds not available in NFA food composition database and all analyses are up-to-date and measured simultaneously with the same method. The national food consumption survey ‘Riksmaten’ on the other hand perceives quick changes in consumptions pattern, but not in food composition, since only a limited number of samples are up-dated every year. The majority of samples in the NFA food composition database have not been updated between 1999 and 2015. A drawback of the Market basket study, is that exposure refers to population means and does not take into account consumption differences. Furthermore, there is a risk of exaggerating the intake with Market basket studies, since no considerations are made towards e.g. food waste. Not all food that is sold will be consumed and Market basket study has no correcting action to adjust for this. Market basket studies can be used in combination with food consumption surveys to give a more detailed picture of, for example consumers with high consumption.

National food consumption surveys as ‘Riksmaten’ and NHANES will result in lower phosphorus intakes compared to surveys as the Market basket, as a consequence of the overestimation of intakes associated with the Market basket as well as the underreport of food intake associated with dietary surveys. Furthermore, the intakes in dietary surveys does not capture quick changes in nutrient composition as the surveys are not based on newly produced analytical data, but on values from food databases. This affect the result since it does not take in to account changes in concentration between different years. The estimated phosphorus intake among the American population presented by NHANES from 2009-2010 at 1414 mg/day is comparable to the estimated intake from ‘Riksmaten’ survey from 2010-2011 at 1374 mg/day since similar methods were utilized.

6 Conclusion

The daily intake of phosphorus in Sweden was estimated to 1820 mg/day in 2015. An increasing trend of phosphorus as has been seen in the USA cannot be seen in Sweden. There is rather a decreasing trend (p=0.006) between 2005 and 2015. The intake calculations are based on annual availability of food items on the Swedish market and do not take into account food waste and might therefore be exaggerated. Another limitation with this analysis is the setup of the method does not enable statistical comparisons with year 1999 and 2010. Furthermore, the samples have been stored for a long time before they were analysed. This might result in concentrated samples as has been indicated with a quality control. The contribution of phosphorus from the food categories dairy products, cereals and potatoes have significantly decreased between 2005 and 2015. However, the phosphorus intake from the food category meat has increased. For dairy products and cereals this decrease might partly be explained by a decrease in total intake of dairy and cereal products. The calcium to phosphorus ratio was estimated to be 1:2.1 2015. A rough estimation of the intake of inorganic phosphorus showed a maximum intake of 400 mg per day. The intake of inorganic phosphorus is difficult to estimate but considered important to monitor and might be used as a complement to estimation of total phosphorus intake in future Market basket studies. Although, the intake of phosphorus in Sweden are well below the UL set by EFSA the intake are three times higher compared to recommended intakes and this should be taken into account then evaluating phosphorus intake further on.

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Appendix

6.1 Popular scientific summary

Healthy intakes regard both minimum and maximum intakes for all nutrients and minerals, so also for phosphorus. The intake of phosphorus in the Swedish population has been estimated to evaluate the nutritional status.

Phosphorus is an essential mineral for a normal body function. Basically, everyone satisfies their need at 600 mg/day with their normal diet. Food items consumed in large quantities as cereals, dairy products and meat are all rich in phosphorus. Therefore, concerns regarding phosphorus are rather linked to an excessive intake than deficiency. An excessive phosphorus intake is for instance associated with an increased risk of cardiovascular diseases and chronic kidney disease. In studies from the USA adverse effects of an excessive intake of phosphorus have been seen. Simultaneously has national food consumption surveys in the USA showed an increasing trend of phosphorus intake. Concerns that the same situation take place in Sweden have been raised, for instance among physicians. In the survey Market basket 2015 was phosphorus for the first time included and together with consumption per capita data it was possible to estimate the phosphorus intake among swedes. To enable a time trend analyse, was food samples from previous Market basked studies re-analysed.

The trend in Sweden does not seem to be increasing, however the intake 2015 was in average 1820 mg/day and that is three times higher than the recommended amount at 600 mg. There are therefore reasons to continuously monitor the phosphorus intake and pay attention to alterations in the trend. Dairy- and cereal products together with meat products are the three main contributors of phosphorus. The contribution of phosphorus from dairy- and cereal products has decreased between 2005 and 2015 while the contribution from meat has increased.

The increasing trend in the USA is linked to the usage of phosphorus containing additives in the food industry. Phosphorus containing additives are for instance utilized in processed meat to increase the water holding capacity and in cola-flavoured soft drinks. Phosphoric acid is added to cola-flavoured soft drinks to achieve the sour taste, other soft drinks contains citric acid instead. Phosphorus that is added as additive is an inorganic form of phosphorus that have a higher resorption rate in the intestine then the organic phosphorus that is bound to carbohydrates, lipids or proteins. This means that phosphorus used in additives is absorbed by the body to a greater extent and therefore contributes more to the phosphorus level in the blood than the organic phosphorus found naturally in most foods. The intake of inorganic phosphorus was estimated not to exceed 400 mg per day and person in Sweden 2015. Similar estimations need to be performed in future studies of phosphorus to establish a time-trend of the intake of inorganic phosphorus.

It can be concluded that the phosphorus intake in Sweden is rather stable and not an accelerating threat to the public health. However, consumers of large amount of cola-flavoured soft drinks should be aware that this increases their phosphorus intake substantially. People with concerns about their phosphorus intake can try to avoid products containing added phosphorus by reading on the label of content since the phosphorus containing additives should be listed there.