Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and Agricultural Sciences
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Rester av stråförkortningsmedel i spannmålsprodukter

Emma Herelius

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Abstract

The use of plant growth regulators (PGRs) to reduce stem elongation in cereals has for a long time been debated in Sweden, particularly since residues of especially one active substance, chlormequat, are often detected in cereal food products. The food company Coop Sverige AB has a desire to limit the possible presence of PGRs in the cereal products of their own brands. Therefore in this thesis, products were sent to Eurofins for analysis of the active substances chlormequat, ethephon, mepiquat and trinexapac. Also, a literature review has been made to investigate how the substances are regulated nationally and in the European Union, the presence in plant protection products (PPPs) in Sweden and the effect on human health. Additionally, a brief analysis on the attitude towards the PGRs in the Swedish cereal industry was made. Residues of the substances were found in 12 out of 23 products. The most frequently detected substance was chlormequat, in the range of 0.006-0.15 mg/kg. Trinexapac and mepiquat were found in two samples respectively. No residue of ethephon was found in any sample. All cereals deriving from Germany contained residues, while the majority of the products originating from Sweden and Italy were free from residues. Since all values were below the corresponding maximum residue levels (MRLs), the residues in the analysed food poses no risk to the consumer.

Keywords: plant protection products, plant growth regulators, straw height regulation, chlormequat, ethephon, mepiquat, trinexapac, residues, cereal products.

Sammanfattning

Användningen av tillväxtreglerande medel för att förkorta strået hos spannmål har länge varit omdebatterad i Sverige, främst för att man ofta har detekterat rester av särskilt en aktiv substans, klormekvat, i spannmålsbaserade livsmedelsprodukter. Livsmedelskedjan Coop Sverige AB har en önskan att begränsa den eventuella förekomsten av stråförkortningsmedel i spannmålsprodukter av sina egna varumärken. Produkter har därför skickats till Eurofins för analys av de aktiva substanserna klormekvat, etefon, mepikvat och trinexapak. En litteraturstudie har även genomförts för att undersöka hur dessa substanser regleras nationellt och inom Europeiska Unionen, i vilka växtskyddsmedel de förekommer i Sverige och om de påverkar människans hälsa. En kort omvärldsanalys av hur attityden till stråförkortningsmedel ser ut inom den svenska spannmålsbranschen har också utförts. Rester av de aktiva substanserna detekterades i 12 av 23 produkter. Den mest detekterade substansen var klormekvat (0,006–0,15 mg/kg). Trinexapak och mepikvat detekterades i två produkter var. Inga rester av etefon hittades i någon produkt. Alla spannmålsråvaror som härstammade från Tyskland innehöll resthalter. Majoriteten av de råvaror som härstammade från Sverige och Italien var fria från stråförkortningsmedel. Eftersom resthalterna i alla produkter var under de motsvarande maximala gränserna för resthaler (MRL) utgör de analyserade produkterna ingen risk för konsumenten.

Nyckelord: tillväxtreglerare, stråförkortningsmedel, klormekvat, etefon, mepikvat, trinexapak, resthalter, spannmålsprodukter

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Abbreviations

ADI	Acceptable daily intake
AOEL	Acceptable operator exposure level
ARfD	Acute reference dose
BW	Body Weight
DAR	Draft assessment report
DDT	Dichlorodiphenyltrichloroethane
EFSA	European food safety authority
EU	European union
GA	Gibberellic acid
GAP	Good agricultural practice
HEPA	2-hydroxyethyl phosphonic acid
IPM	Integrated pest management
LOQ	Limit of quantification
LRF	Lantbrukarnas riksförbund
MQ	Mepiquat
MRL	Maximum residue level
PGR	Plant growth regulator
PPP	Plant protection product
RMS	Rapporteur member state

1 Introduction

1.1 Problem Description

The use of straw height reducing plant growth regulators (PGRs) on cereals was nationally limited in 1987 to only be used on rye as there was a fear for an increased use of fertilizers and residues in cereal products (Jordbruksverket 2012). However, since 2012 the restrictions have started to ease as the use of the PGR Moddus M was extended from only rye to other cereals too (Kemikalieinspektionen 2011a). Only recently, since 1st October 2016, the use of another PGR, Cycocel, has been extended to other cereals as well (Kemikalieinspektionen 2016b). The attitude in the cereal industry is however divided. Most of the significant actors still believe that the use of PGRs should be restricted, at least in wheat (The absolut company n.d., Lantmännen n.d.b., Pågen n.d.b., Svenska kvarnföreningen n.d.). While some actors believe that the national terms and attitudes are unreasonable as they make it difficult to compete with other countries in the EU (LRF n.d.). The Swedish Chemicals Agency proposed in 2012 to prohibit the use of PGRs again, but the government decided not to proceed with the proposal, but stated that if the use of PGRs would increase, they should take action (Kaliber 2014).

The member-owned food company Coop Sverige AB has a desire to limit the potential presence of PGRs in the cereal products of their own brands. To be able to make reasonable decisions, it is necessary to map the occurrence in the products, gather knowledge about the substances and how they are regulated in the EU. Based on the gathered information and results, a recommendation for how to proceed with the request will be made.

1.2 Aims and Purpose

The aims of this thesis are to investigate:

- which active substances, as PGRs, are used in cereals to reduce stem elongation in the European Union (EU) and Sweden.
- how the substances and corresponding plant protection products (PPPs) are regulated by law, nationally and by the EU.
- on which cereals, each substance is allowed to be used in Sweden.
- What the final purpose of the use is and if there are alternative methods to achieve the same result.
- if the substances have other favourable effects than the main purpose.
- if the substances, as residues in cereal-based food or in concentrated form as PPPs might have a negative effect on the human health.
- the attitude towards PGRs by some important actors in the Swedish cereal industry.
- the amount of the PGR substances in selected food products, related to cereal type and origin.

The purpose of this thesis is to provide Coop with information on PGRs and to investigate the possible presence of these in the products of their own brands, so they can make reasonable decisions regarding requirements on their suppliers and products about PGRs.

2 Literature background

2.1 What is a Pesticide?

The European Commission defines the word ‘Pesticide’ as follows:

> *A ‘pesticide’ is something that prevents, destroys or controls a harmful organism (‘pest’) or disease, or protects plants or plant products during production, storage and transport*. (European Commission 2016a).

The term is wide and covers both plant protection products (PPPs) and products for non-plant use, such as biocides. Plant protection products are mainly used to prevent the plant or plant products from being destroyed by pests and diseases, destroy or prevent weed growth, but also influence the life process of the plants. The PPPs contain one or sometimes several active substances in different concentrations that determine the action of the product. The substances can either be biological, including microorganisms such as certain viruses or bacteria, but occur mainly as chemical preparations (European Commission 2016a; EFSA n.d.a). Within the group of plant protection products there are plant growth regulators which are further explained in section 2.4.

2.2 The Emerge of Plant Protection Products

Agriculture was first developed by humans approximately 10 000 years ago in Mesopotamia where some of the precursors of the main food crops belonged to the inherent flora. People started to domesticate the plants by selecting the ones with desirable characteristics, removing the undesirable plants and sowing gathered seeds from a certain fraction. A comparison of some differences between a wild and domesticated cereal is shown in Figure 1. At the end of the 1800s the breeding gradually aimed for an increased yield and the cultivated plants started to lose their ability to survive in the wild (Tauger 2010, Fogelfors 2015).

Figure 1. Domesticated cereals (right) differ from their wild counterpart (left) mainly by the larger seed, smaller glume and tougher rachis to hold the grain strongly connected to the plant (Tauger 2010, Figure: Stina Hansi 2016).

By the time the stands of single species increased in size, the extent of pests and diseases also increased, leading to losses of harvest, which sometimes also led to starvation (Fogelfors 2015). The first generation of pesticides included highly toxic or ineffective compounds, such as arsenic and hydrogen cyanide (Oregon State University 2012). The second generation included synthetic compounds, such as DDT (dichlorodiphenyltrichloroethane), which is one of the most important pesticides in history and was discovered in the 1930s to kill insects very efficiently. DDT was used in large amounts in agriculture as an insecticide between the 1950s and 1970s. However, already in the 1950s insects started to evolve resistance to the chemicals and it also killed beneficial insects and birds. As even people exposed to the chemicals were poisoned, died or sometimes developed cancer, DDT was eventually banned in the 1970s. The pesticides were thereafter developed to be more efficient, but also the requirement that the pesticides should have as little impact on the environment and human health as possible was increased (Tauger 2010, Weidow 1998). The EU-directive from 2009 about sustainable use of pesticides, implies that all users of pesticides in agriculture and horticulture shall apply integrated pest management (IPM). IPM implies that the use of chemical pesticides should decrease and instead increase preventional methods and alternative solutions for a sustainable use of chemical pesticides (Fogelfors 2015).

2.3 Plant Protection Products in Agriculture Today

There is currently a large number of PPPs produced to target different kinds of objects. These are mainly fungicides, bacteriocides, herbicides, haulm destructors, moss killers, insecticides, acaricides, molluscicides and plant growth regulators. The total sales of pesticides 2013 was approximately 360 000 tons, where Spain, France, Italy, Germany, Poland and The United Kingdom together accounted for 75.2% of the sales in the EU (Figure 2). Sweden accounts for 0.6% of the total sales. The group of pesticides most sold are fungicides and bactericides which together account for 42%, and are followed by herbicides, haulm destructors and moss killers that account for 36% of the total sales. Plant growth regulators however, accounts for 3% of the total sales. As Spain stands for the largest share of sold pesticides, Germany accounts for the largest share of sold PGRs, followed by France (Figure 3). Sweden accounted for 0.2% of the PGR sales in the EU (Eurostat 2016). It is however important to have in mind that the group of PGRs include products used not only on food crops, but also, for example on ornamental plants and grass seed as well (Table 1).

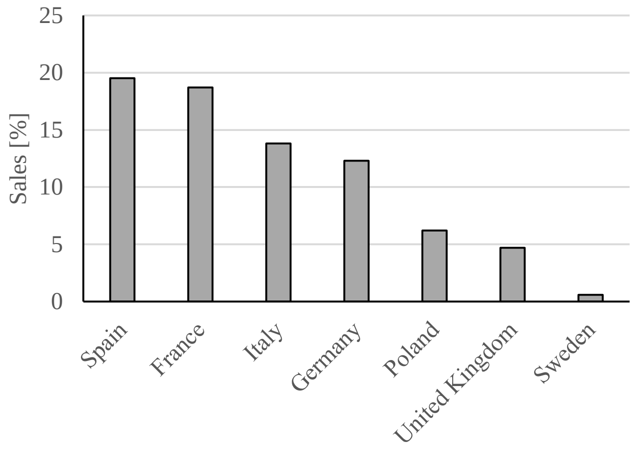

Figure 2. The total sales of pesticides in the six countries with the largest share in the EU and Sweden 2013 (Eurostat 2016).

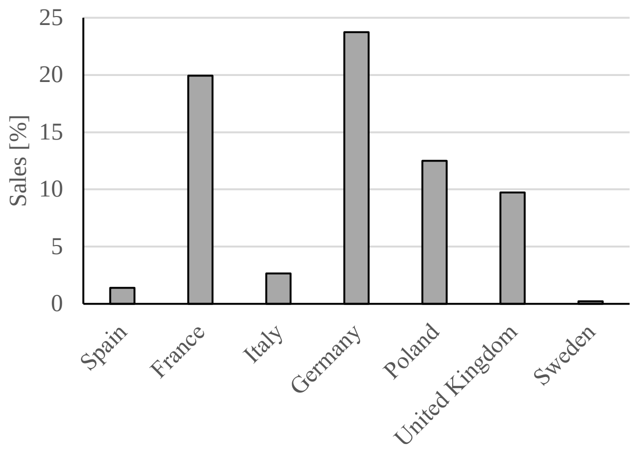

Figure 3. The total sales of plant growth regulators in the six countries with the largest shares of sold pesticides and Sweden 2013 (Eurostat 2016).

2.4 Plant Growth Regulators

Plant growth regulators are organic compounds other than nutrients that influence any physiological processes of the plant. The group of PGRs includes both naturally occurring substances like phytohormones or other growth substances, but also synthetic compounds or chemical analogues. The use of both naturally occurring and synthetic PGRs has generally increased in agriculture and horticulture since the 1940s. It is used to control the developmental processes of the plant from germination through vegetative growth, reproductive development and maturity, ageing and postharvest preservation (Basra 2000). According to the regulation (EC) No 540/2011 there are 28 active substances approved as plant growth regulators in the European Union. However, only 9 of them occur in approved PPPs in Sweden (Table 1).

In Table 1 the active substances that are approved as PGRs in Sweden are presented. Their main purposes are inhibition of germination of onions and potatoes, growth regulation of ornamental plants and straw height reduction in cereals. In this thesis, only the straw height reducing PGRs are reviewed.

Table 1. Active substances and the usage of the corresponding plant protection products in Sweden

Active substance (ISO)	**Approved area of use for corresponding PPPs in Sweden**
Maleic hydrazide	Inhibiting germination of onions
Daminozide	For growth regulation of ornamental plants in green houses
Ethephon	For straw height regulation in rye
Gibberellin (GA4&GA7)	For growth regulation of pine and spruce trees in seedling plantation
Spearmint oil	Inhibiting germination of stored potatoes
Chlormequat	For straw height regulation in wheat, triticale, rye, oats and grass seeds
Chlorpropham	Inhibiting germination of stored potatoes
Mepiquat	For straw height regulation in rye, wheat, triticale and barley
Trinexapac	For straw height regulation in rye, wheat, triticale, barley, oats and grass seeds

(Kemikalieinspektionen n.d.)

2.5 Phytohormones: Affected by Plant Growth Regulators

Phytohormones (plant hormones) are compounds that act at a very low concentration and that have multiple regulatory roles during growth, development and the defence of the plant. There are five well-established phytohormones involved in the growth of plants; auxin, gibberellins, cytokinins, ethylene and abscisic acid. However, two of the hormones may be the most important regarding reduction of stem elongation by using PGRs; gibberellins and ethylene (Rademacher 2000, Sadava et al. 2014). Gibberellins have several effects on the plant growth and development; one of the effects is stem growth due to cell elongation, rather than cell division. Ethylene also has numerous effects on the plant. Though its main effect is to promote senescence, ethylene also inhibits stem growth by controlling the formation of the auxin gradient during seedling development that otherwise promotes stem elongation (Sadava et al. 2014).

2.6 Lodging of Cereal Crops

Some PGRs are used in cereal management to shorten the straw and thus increase lodging resistance. Lodging is generally caused by heavy rains and addition of too much nitrogen to the crops, which results in thinner cell walls and thereby a weaker straw. Severe lodging can cause serious problems in grain growth and quality. The ability of the lodged crop to capture photosynthetically active radiation is not at all ideal, and may result in reduced photosynthate production. Also the xylem and phloem transport of water, nutrients and assimilates may be hindered, resulting in reduced grain filling. Moreover, the lodged crops dry more slowly, which increases the risk of fungal diseases (Peltonen-Sainio & Rajala 2000; Weidow 1998). The falling number may be effected negatively, leading to a decreased bread quality (Jordbruksverket 2015). A common fungal disease that may infect cereal crops is *Fusarium*, which under certain conditions may produce mycotoxins which some are highly toxic. If lodging occurs during humid condition when fungal spores are present at the base of the straw, the risk of the grains to be infected is high (Fogelfors 2001). Except for the risks of failing grain quality, lodging may also result in loss of harvest, which also leads to a financial loss for the farmer. Lodging may be prevented by choosing sturdier cereal varieties, adjusting the seed rate and fertilization. Also by treating against certain fungi, as eyespot and rust may improve the stem strength (Jordbruksverket 2015). Straw shortening plant growth regulators are also an option, by shortening and stiffening the straw, PGRs may indirectly improve grain quality (Peltonen-Sainio & Rajala, 2000).

Lodging in rye stands is most common due to its considerably longer and more fragile straw. The need to prevent lodging by using PGRs has therefore generally been greater in rye, compared to other cereals (Jordbruksverket 2012).

2.7 The Plant Growth Regulators Used for Straw Height Reduction in Cereals

Substances that are approved as PGRs, and that may be used for reducing straw height in cereals, in Sweden, are chlormequat, mepiquat, ethephon and trinexapac ((EC) No 540/2011, Kemikalieinspektionen 2015, 2014b, 2016b, 2016d). Another approved PGR in the EU is Imazaquin, which is used as an anti-lodging agent in winter wheat in France, Belgium, Ireland, Lithuania and United Kingdom. However, the substance is not approved in Sweden, therefore the focus in this thesis will be on the first four mentioned (European Commission 2016d).

The corresponding PPPs in Sweden to chlormequat, ethephon, mepiquat and trinexapac are presented in Table 2. These straw shortening substances are widely used as anti-lodging agents. The corresponding PPPs accounts for approximately 25% of the global PGR sales (Rademacher 2015). In Sweden, the sales of Chlormequat has been considerably higher than the three other substances during 2010-2014 (Figure 4). The sales of Trinexapac however, increased after 2011 probably due to the renewal of the product approval of Moddus M, which meant a wider area of use (Kemikalieinspektionen 2011a). In 2014, chlormequat was one of the 10 most frequently detected PPP residue in plant products (EFSA 2016).

Table 2. Straw height regulators, their corresponding PPPs and their first year of approval in Sweden

Active substance	Corresponding PPPs	First year of approval in Sweden
Chlormequat	BASF Cycocel Plus	1976
Ethephon	Cerone	1983
	Terpal (II)	2003
Mepiquat	Terpal (II)	2003
Trinexapac	Moddus Start	2014
	Moddus M	1996
	Trimaxx	2013

(Kemikalieinspektionen n.d.)

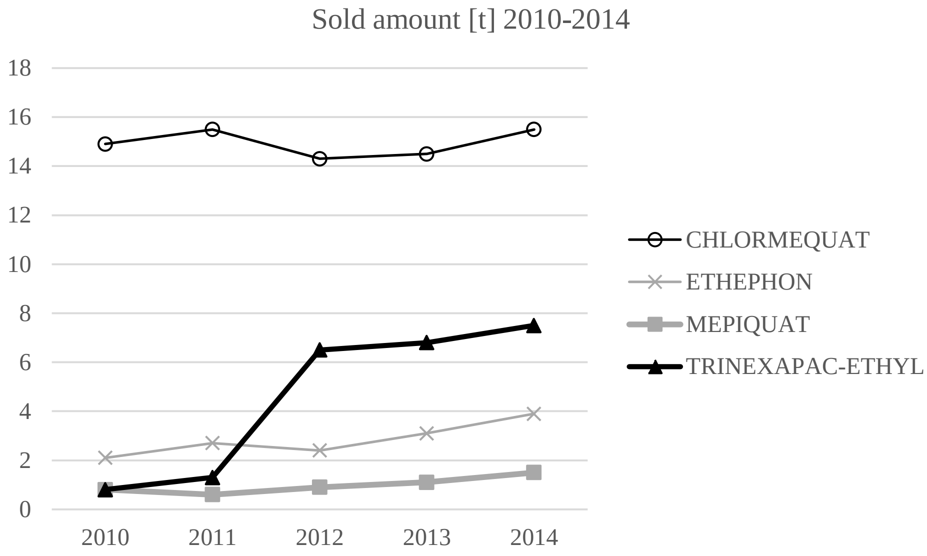

Figure 4. Sold amount [t] of the straw height reducing PGRs in Sweden 2010-2014 (Kemikalieinspektionen 2016a).

Aside from the anti-lodging effect of these PGRs, the substances may also increase yield potential by improving partitioning of dry matter into harvestable yield. This may be due to the lesser demand of assimilates for stem elongation, which instead can be used for floret and spikelet set and grain growth. The timing of application in the crop growth stage is however an important factor (Peltonen-Sainio & Rajala, 2000).

Depending on the toxicological properties of the substances, they are classified by the EU in different categories, as well as the corresponding PPPs, which is nationally classified. The classifications apply for the concentrated form of the substances and PPPs, and not as residues in food products.

The following substances may have a wider area of use, however, only the approved use on cereals will be presented.

2.7.1 Chlormequat (Chlormequat chloride)

Chlormequat contains a positively charged ammonium group in its structure (Figure 5). This group enables the blocking of *ent*-Kaurene synthesis from geranylgeranyl pyrophosphate, which is the precursors of gibberellin. The whole biosynthesis of gibberellin is thereby blocked, inhibiting cell elongation, resulting in shorter stems (Rademacher 2000; Peltonen-Sainio & Rajala, 2000). In the plant protection product, Chlormequat is added in the form of a salt, chlormequat chloride (Figure 5), however, the active molecule is chlormequat alone.

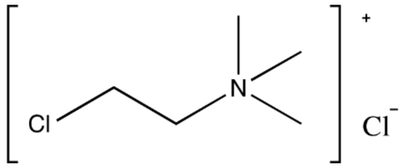

Figure 5. Chlormequat-chloride.

The toxicological effects of chlormequat was thoroughly evaluated by EFSA in 2008. It was stated that the substance was almost completely absorbed and then mostly excreted in the urine, also no evidence of bioaccumulation was found. The molecule was barely metabolised in the body. In the mutagenicity and long-term tests, no genotoxic or mutagenic effect was found in rats. It was found that the maternal fertility may be affected at a high dosage of chlormequat in some rodents. Also, the acute oral toxicity tests on rats and dermal tests on rabbits resulted in the classification “Harmful if contacted with skin and if swallowed” (EFSA 2008a). In a review from 2006 in which studies on the effects of chlormequat on mammalian fertility were summarized, it was concluded that female fertility in pigs is more sensitive to chlormequat than in female rodents (Sørensen & Danielsen 2006). Cases of chlormequat poisoning by ingesting or inhaling corresponding PPPs has recently been reported in France, the incidents were fatal mostly within the hour of intake, mainly through cardiac arrest (Nisse et al. 2015).

In the EFSA conclusion on residues and metabolism of chlormequat in wheat, it was stated that unmetabolised substance was detected at harvest (EFSA 2008a).

The effect of chlormequat on yield varies between studies. In a review from 2000, the collected effects of chlormequat was widely spread from no effect to a 20% increase in yield in different cereals (Peltonen-Sainio & Rajala, 2000). A small reduced grain weight was shown in oats when using chlormequat by Browne et al. in 2006. According to one study in 2008 performed on wheat with different nitrogen rates, the effect of shortening the straw by chlormequat lead to an indirect increase in yield (Shekoofa & Emam 2008). In another study, by Espindula et al. 2009 where chlormequat was added at different rates on wheat, it was found that the grain yield was not affected. Recently, the same conclusion was reached again by Miziniak & Matysiak 2016, no effect on yield in wheat.

In the EU the active substance is regulated in directive 2010/2/EU to only be approved in pesticides used on cereals and non-edible crops. Additional terms are that the member states need to pay particular attention to the operator safety, as well as the protection of birds and mammals when approving PPPs containing chlormequat. Additional information on the behaviour of the substance in soil under certain conditions, predicted concentration in certain water environments, monitoring methods for determination in animal products and water, and further risk assessment to birds and mammals (European Commission 2016g). In Sweden, there is just one approved PPP containing chlormequat, which before 1st October 2016 was only allowed to be used on rye. Thereafter, the Swedish Chemicals Agency has decided on a renewal of the product approval, implying a broadened use, from only rye, to wheat, oats and triticale as well (Kemikalieinspektionen 2016b).

In regulation (EC) No 1272/2008, pure chlormequat is classified as acute toxic category 4: H302 and H312, implying the substance to be harmful if swallowed and in contact with skin. Although the substance is not classified as an environmental hazard according to the Commission (No 1272/2008), the Swedish Chemicals Agency has classified the corresponding PPP to be harmful to aquatic life with long lasting effects (Kemikalieinspektionen 2016c). The latest review of chlormequat was performed by the Commission in 2015.

2.7.2 Ethephon

Ethephon (Figure 6) does not interfere with the biosynthesis of gibberellin. Instead, when absorbed in the cell it decomposes into ethylene, phosphoric and hydrochloric acid, indirectly controlling cell elongation (How ethylene affect the straw height was explained in section 2.5) (Rademacher 2015; Peltonen-Sainio & Rajala, 2000).

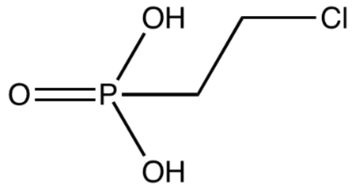

Figure 6. Ethephon.

In the conclusion from EFSA 2008 on the risk assessment on ethephon, the substance was considered not to be genotoxic or oncogenic in rats and mice. The reproductive system and fertility were not affected either (EFSA 2008b).

Equal residue levels of ethephon and its metabolite 2-hydroxyethyl phosphonic acid (HEPA) were detected in grains at harvest. As HEPA was considered to be more toxic than ethephon itself, HEPA was taken into account when assessing human exposure and setting maximum residue levels (MRLs) for ethephon in cereals (EFSA 2008b).

The effect on grain yield varies between studies and cereal species, however, most studies indicate a reduced or no effect (Peltonen-Sainio & Rajala, 2000). In a study on spring wheat from 2004 it was shown that ethephon reduced yield by the number of kernels per spike (Tripathi et al. 2004). It was also shown by Shekoofa & Emam 2008 that compared with chlormequat the effect of ethephon was low.

The substance is regulated by the commission in directive 2006/85/EC to only be approved as a plant growth regulator. In the EC review report on ethephon it is stated that corresponding PPPs are not permitted to contain the toxic manufacturing impurities Mono 2-chloroethyl ester, 2-chloroethyl phosphonic acid and 1,2-Dichloroethane in a higher amount than 20 g/kg and 5 g/kg, respectively (European Commission 2016e).

In Sweden there are two approved PPPs containing ethephon. One of the products contains ethephon as the only active substance and is only approved to be used on winter rye (Kemikalieinspektionen 2015). Besides ethephon, the other product also contains mepiquat and is approved for the use on rye, winter wheat, triticale and barley (Kemikalieinspektionen 2014b).

In regulation (EC) No 1272/2008, pure ethephon is classified as acute toxic category 4: H302 and H332, meaning that it is harmful if swallowed and if inhaled. It is also acute toxic 3: H311, implying that it is toxic if contact with skin. Furthermore, it is classified to cause severe skin burn and eye damage. Additionally, it is toxic to aquatic life with long lasting effects.

2.7.3 Mepiquat (Mepiquat Chloride)

In the same way as chlormequat, mepiquat also contains an ammonium group and blocks the synthesis of *ent*-Kaurene and therefore gibberellin (Rademacher 2000). It is also added as a salt, mepiquat chloride (Figure 7) in the PPP, however, the active molecule is mepiquat.

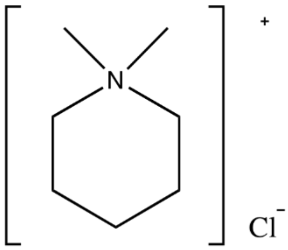

Figure 7. Mepiquat-chloride.

In the EFSA conclusion from 2008, the toxicity tests on rats resulted to be harmful if swallowed, but not to be irritable to the eyes or skin. Neither was it shown to have any genotoxic or carcinogenic potential in rats and mice. Nor did it show to have any reproductive or developmental toxicity potential (EFSA 2008c).

In the EFSA conclusion it was also noted that the major component in the crops at harvest was unmetabolised mepiquat. However, it was concluded that residues above the limit of quantification (0.05 mg/kg) would not occur in succeeding and rotational crops (EFSA 2008c).

Mepiquat is regulated in the Commission directive 2008/108/EC only to be used as a plant growth regulator. It is also noted that all member states shall pay particular attention when assessing the application for authorisation of PPPs for the use on other cereals than barley. This statement may be based on the lack of residue trials on other cereals than barley (EFSA 2008c). Further terms implied that the member states should pay particular attention to the residues in food and to evaluate the consumer dietary exposure (European Commission 2016f). In Sweden there is only one product approved containing mepiquat, which also contains ethephon. The product is approved to be used on rye, spring wheat, triticale and barley (Kemikalieinspektionen 2014b).

Mepiquat is also detected as a by-product in roasted coffee, at levels of 1.4 mg/kg, formed in the Maillard reaction during the heat treatment (Wermann et al. 2014). Recent studies have also shown that mepiquat may be formed in some cereal based foodstuffs treated in sufficiently high temperature (240-400°C), such as beverages based on roasted barley. Mepiquat was not found in bread as the crust did not exceed temperatures >220°C (Bessaire et al. 2016).

According to regulation (EC) No 1272/2008, pure mepiquat is classified as acute toxic category 4: H302, meaning that it is harmful if swallowed. It is also aquatic chronic 3 implying the substance to have a harmful effect on aquatic life with long lasting effects.

2.7.4 Trinexapac (Trinexapac-ethyl)

Trinexapac is added in the form of trinexapac-ethyl (Figure 8) to the PPP, when in contact with water, the substance converts into its active form as an acid. Trinexapac interferes in the late gibberellin synthesis by inhibiting the 3beta-hydroxylation of GA20 to GA1 (Rademacher 2000).

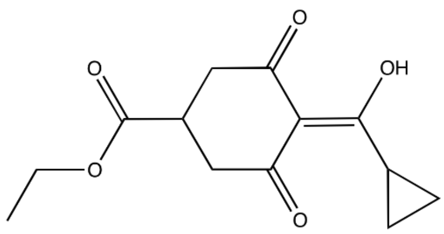

Figure 8. Trinexapac-ethyl.

In 2005 it was noted in the EFSA conclusion on trinexapac that the substance is of low acute toxicity. It is not an irritant to the eyes or skin, neither a skin sensitizer. It was not shown to have genotoxic or carcinogenic potential, and there was no direct effect on the reproductive potential or fertility (EFSA 2005).

In the conclusion, it was also noted that the major component in the crops at harvest was trinexapac. However, following good agricultural practice (GAP) when applying the PPP, no substantial residue levels should be expected in rotational crops (EFSA 2005).

The yield of wheat grain could according to one study be reduced if triexapac is used in a high rate (Espindula et al. 2009). According to another study the yield increased with increased application dose and nitrogen to a certain point (Zagonel & Fernandes 2007).

Trinexapac is regulated in directive 2006/64/CE to only be used as a plant growth regulator. It is also noted that the member states should pay particular attention to birds and mammals in the authorisation assessment of PPPs. In Sweden there are three approved products containing trinexapac with the purpose to be used for food crop production. They are all approved to be used on rye, wheat, triticale, barley and oats (Kemikalieinspektionen 2011b, 2013, 2014a).

According to regulation (EC) No 1272/2008, the substance is not classified as toxic in any category. However, the corresponding PPPs in Sweden has been classified as toxic in different categories, see Table 3.

Table 3. Classifications of the plant protection products authorised in Sweden containing trinexapac

Plant protection product	**Classification**
Moddus Start	- Serious eye damage or irritation- category 2 - Harmful to aquatic life with long lasting effects- category: chronic 3
Moddus M	- Harmful to aquatic life with long lasting effects - category: chronic 2 - Allergic reaction in contact with skin- category 1B
Trimaxx	- Serious eye damage or irritation- category 2 - Harmful to aquatic life with long lasting effects - category: chronic 3 - Allergic reaction in contact with skin- category 1A

Kemikalieinspektionen 2011b, 2013, 2014a

2.7.5 The Commission Conclusion Regarding Residues

In the final review reports on chlormequat, ethephon, mepiquat and trinexapac it is stated that the active substances does not have harmful effects on human or animal health with regards to residues arising from the proposed uses and application consistent with good plant protection practice. Nor do they have unacceptable effects on the environment under the proposed and supported conditions of use. However, more information on residues concerning food of animal origin is needed to confirm the risk assessment of mepiquat (European Commission 2016b; 2008a; 2008b; 2015).

2.8 Approval of Active Substances

The procedure of legalising a plant protection product in the European Union is long and complicated. Initially, the active substance of the PPP has to be approved by the commission and is regulated in (EC) No 1107/2009. The procedure of approval implies a scientific evaluation of the active substance that include a safety assessment of the direct or indirect harmful effect on humans, but also the effect on animal health and environment. The criteria for approval are substantial and are regulated in Annex II in (EC) No 1107/2009.

The applicant who wants to have an active substance approved, submits a dossier to a member state of their choice, which is called the Rapporteur Member State (RMS). The dossier shall contain information needed to establish Acceptable Daily Intake (ADI), Acceptable Operator Exposure Level (AOEL) and Acute Reference Dose (ARfD). The ADI is the amount of substances in food that may be consumed daily during a lifetime without an appreciable risk, while the ARfD is the amount of substance in food that can be ingested over a short period of time, e.g. 24h, without appreciable risk. The AOEL is the maximum amount of active substance to which the operator, who is involved in the activities relating to the application of PPPs, may be exposed without any adverse health effects ((EC) No 1107/2009; (EC) No 396/2005). In Table 4, the ADI, ARfD and AOEL for the four PGRs are presented.

When the process has started, the RMS notifies the other member states, the Commission and the European Food Safety Authority (EFSA). A Draft Assessment Report (DAR) is written by the RMS, assessing if the active substance can be expected to reach the approval criteria. The DAR will be thoroughly evaluated by peer reviewing, expert groups and commented on, involving EFSA, member states, the Commission and RMS. EFSA shall come to a conclusion on whether the active substance can be expected to reach the approval criteria with the help of expert consultations and further peer reviewing. At the end of the process a review report and draft regulation shall be presented on the approval or non-approval of the active substance by the Commission. The standing committee for Food Chain and Animal Health then votes on approval or non-approval. The whole process from application to decision by the standing committee takes approximately 2.5 to 3.5 years. An active substance is generally approved for a period of 10 years, it is then possible for an applicant to apply for a renewal (European Commission 2016c, Fontier 2011).

Table 4. Acceptable daily intake (ADI), Acceptable reference dose (ARfD) and Acceptable Operator Exposure Level (AOEL) for the straw height reducing substances

Substance	**ADI [mg/kg bw per day]**	**ARfD [mg/kg bw]**	**AOEL [mg/kg bw per day]**
Chlormequat	0.04	0.09	0.04
Ethephon	0.03	0.05	0.03
Mepiquat	0.20	0.30	0.30
Trinexapac	0.32	Not applicable	0.34

European Commission 2016b, 2016e, 2016f, 2016g

2.9 Approval of Pesticides

The application for a new pesticide is processed on a member state level and is regulated in chapter III in (EC) No 1107/2009. When an applicant wishes to place a new pesticide on the market, the application is sent to the responsible authority in the current member state. In Sweden the responsible authority is the Swedish Chemicals Agency (Kemikalieinspektionen) (SFS 2009:947). As for the approval of an active substance, the authority will evaluate the application based on the scientific documentation of the pesticides effect on the human health, animal health and the environment. One of the requirements for approval is that the active substance is approved in the EU ((EC) No 1107/2009).

2.10 The Supervision on the Use of Plant Protection Products in Sweden

2.10.1 The Swedish Chemicals Agency, The Swedish Board of Agriculture and The National Food Agency

Regarding the use of plant protection products in agriculture there are numerous authorities involved with different area of responsibility. The Chemicals Agency decides on the conditions for each pesticide: dosage per hectare, the number of treatments, what kind of equipment to use, in which stage of growth and maximum dosage for treatment of both PPP and active substance. They are also responsible for the supervision of the primary distributors of PPPs and guidance of supervision of other distributors by the municipality (Jordbruksverket n.d., Kemikalieinspektionen 2016d, SFS 2009:947).

Concerning the use of PPPs at the farm, the Swedish Board of Agriculture (Jordbruksverket) decides on regulations concerning permission to use PPPs, requirements of documentation (spray journal), compulsory function tests of spray equipment and integrated pest management. The authority is also responsible for the education and permission on the professional use of PPPs. Additionally, they are responsible for the guidance of the supervision of plant protection by the municipality (Jordbruksverket n.d.).

According to article 30 in (EC) No 396/2005 on maximum residue levels of pesticides in or on food, all member states shall establish multiannual national control programmes for pesticides residues, which shall be updated every year. In Sweden the National Food Agency (Livsmedelsverket) has the responsibility for the national control of food and drinking water (§9 SFS 2009:1426). The programme of control is mainly based on risk; nationally, most frequently consumed products, how the products are prepared and cooked, results from previous years etc. The results are then reported to EFSA and published on the Food Agency's website (Livsmedelsverket 2016).

The European Commission decides on the Maximum Residue Levels (MRL) for each pesticide which are assessed by EFSA, and is also generally regulated in (EC) No 396/2005. The MRL implies the upper legal level of concentration for a pesticide residue in or on the food, based on the lowest consumer exposure necessary to protect vulnerable consumers and good agricultural practice; which is the minimum amount needed to reach the effect of the pesticide on the crop. In the assessment of MRLs, EFSA uses a calculation model to estimate the short- and long-term exposure of consumers. It is based on numbers received by the member states, for example national food consumption digits and unit weights (EFSA n.d.b). The maximum residue levels for some of the common cereals is presented in Table 5.

Table 5. Maximum residue level (MRL) of the straw shortening PGRs for the common cereals [mg/kg]

Cereal	**Chlormequat**	**Mepiquat**	**Ethephon**	**Trinexapac**
Rye	3.0	3.0	1.0	0.5
Wheat	2.0	3.0	1.0	3.0
Barley	2.0	3.0	1.0	3.0
Oats	9.0	2.0	0.05*	3.0

*indicates lower limit of analytical determination

European Commission 2016b, 2016e, 2016f, 2016g

2.10.2 The County Administrative Boards, Swedish Work Environment Authority and Municipalities

The County Administrative Boards and the municipalities have the right to decide on water protection areas. The County Administrative Board shall also give guidance on environmental supervision in the county. The Swedish Work Environment Authority (Arbetsmiljöverket) decides on regulations regarding the handling and use of chemical pesticides. They are also regularly providing courses for the operators handling pesticides (Jordbruksverket n.d.).

The municipalities are often the operational regulatory authorities that monitor if the farmer follow the laws and regulations (2 kap. 31§ Miljötillsynsförordning 2011:13). During the supervision, on the area of plant protection, numerous questions are asked about how the farmer is working with integrated pest management, and for example the handling, distribution and storage of PPPs. The spray journal is reviewed, in which the information about the usage of plant protection products is documented. The farmer is obligated to fill in the required information in the spray journal about what kind of product has been used on what type of crop and why it has been used. There is also a requirement to write who carried out the spread, the dosage, where and when it was performed and safety distances (Jordbruksverket n.d.). In chapter 8 in regulation SFS 2012:259 on environmental penalties there are numerous of violations listed. For example, if the farmer is using PPPs without permission, the spray journal is missing or vital information in the spray journal are missing, the inspector can make a decision on an environmental penalty.

2.11 The Attitude towards the Plant Growth Regulators in Society and Industry

2.11.1 The Judicial History of Plant Growth Regulators in Sweden

In 1987, a decision was made to prohibit the use of straw shortening PGRs in cereal farming in Sweden, except in rye due to its substantially longer and more fragile straw. The decision lasted until 2000 when the first PGR was noted in annex I to directive 91/414EEG. The national regulation was considered to hinder application trials for certain PPPs and therefore to be in conflict with EU law. In 2005, the Swedish Chemicals Agency rejected four applications to extend the area of use to additional cereal types, other than rye. The rejections were based on a study that indicated an increased use of fertilizers and therefore nitrogen leakage if the use was to be extended. Two of the applying companies appealed the rejection to the government, which in 2008 rejected the appeals. The corporations proceeded with

a request for a judicial review of the supreme administrative court which in 2010 repealed the decision of the government as they found it to be in conflict with directive 91/414EEG and 14 chap. §10 the Swedish environmental code (miljöbalken). As a result of the decision of the supreme administrative court, the government repealed the decision of the Chemicals Agency from 2005 which again examined the applications. The Chemicals Agency decided in 2011 to extend the use of Moddus M in rye to wheat, triticale, barley and oats additionally (Jordbruksverket 2012). A more extensive background of the legal disputes can be read in the thesis of Löfgren 2012.
In conjunction with the broadened use of Moddus M, the Chemicals Agency submitted a proposal to prohibit the use of PGRs in all cereals, except rye. The Board of Agriculture was commissioned to assess possible agricultural impacts of the proposal and to present the result to the Ministry of Rural Affairs (Landsbygdsdepartementet) on 28th September 2012. The following decision by the government resulted in not adopting the proposal of prohibition, instead the government implied that advice and guidelines to the farmers should be more appropriate to reach the goal of low use of PGRs. However, the (now former) environmental minister states that if the use of PGRs should increase, the government would take measures (Kaliber 2014).

2.11.2 National Authorities

In the current national plan of action for sustainable use of plant protection products (2013-2017) it is stated that the use of the chemical straw height reducing PGRs in other cereals than rye is low and should be kept at that level. This is due to the preventional methods, including choice of cultivar, time for sowing, seed amount, fertilization and carefully chosen treatment against fungal disease (Landsbygdsdepartementet 2013).

To fulfil the national plan of action, the Swedish Board of Agriculture has written a list of measures in which they describe how the authority is going to implement commitments about straw height reducing PGRs. It is stated that the authority is going to provide objective facts on straw shortening PGRs based on conducted field trials. Also to continue the dialog with actors in the cereal industry, not to purchase grain for food production in which PGRs has been used (Jordbruksverket 2016).

2.11.3 The Cereal Industry

The Swedish Milling Association (Svenska kvarnföreningen) is a venue for actors in the cereal industry, in which most of the Swedish mills are members. On their website, a policy is stated, implying a recommendation not to use PGRs (Svenska Kvarnföreningen n.d.).

Lantmännen is one of the major actors in the industry as they are the largest purchaser of cereals in Sweden and has multiple food brands. They are not a member of Svenska kvarnföreningen. Lantmännen has three concepts for cereal quality: Standard, Premium and Organic. The Standard quality implies a concept that strives for similar production terms and quality as in the rest of EU. The Premium concept implies higher requirements, regarding for example plant protection (Lantmännen n.d.a). In the terms of purchase for Premium cereals, it is stated that Trinexapak or similar products are not allowed (Lantmännen n.d.b). When delivering cereals to Lantmännen, the farmer must declare the use of PGRs in a delivery assurance form (Lantmännen lantbruk n.d.). On their website, it is stated that cereals for two of the food brands; Kungsörnen and Axa are free from PGRs as a precaution for health and environment (Lantmännen n.d.c). However, it is not stated if their other brands are free from the substances.

Pågen is a major Swedish bakery which in 2015 used 81% Swedish raw material. On their website they state that they do not use wheat that has been treated with PGRs (Pågen n.d.a & n.d.b).

The Swedish corporation, Absolut Company AB, produces vodka by using wheat starch, and this is the largest export product nationally in the food category (The Absolut Company n.d.a). In their latest cultivation concept for the harvest year of 2016, it is stated under the general requirements that the use of straw height reducing PGRs is prohibited (The Absolut Company n.d.b).

2.11.4 Agricultural Advisors

Two important actors in the Swedish cereal industry that may provide the farmer with advice on plant protection are Lantbrukarnas riksförbund (LRF) and Hushållningssällskapet.

LRF is a politically unbound, interest- and business organization for businesses within the green industry. In the thesis by Löfgren 2012, an interview was made with the former chief of plant protection on LRF. In that time, their opinion was that PGRs need to be processed as any other PPP to avoid endangering the free market. Today the organisation seems to have a similar standpoint as they state on their website that the Swedish cereal production is subjected to an unfair competition compared to other countries in the EU when PPPs disappear from the Swedish markets (LRF n.d.).

Hushållningssällskapet is an independent organisation that focus on the interests of the farmers, therefor they do not have a policy regarding PGRs (Hushållningssällskapet n.d.).

3 Method

3.1 Selection and Categorizing of Food Products

There were 23 cereal products selected for analysis. The assortment was reviewed and products from all current suppliers to the brands were represented, although organic products were excluded as no plant protection product were assumed to have been used. As the budget was limited, only one sample from each product was selected and was considered enough for the purpose to investigate a possible presence of PGRs in the product from a certain supplier. In the cases when several varieties of one product existed, only one was chosen.

To protect the brands and suppliers, the products were categorised into 4 groups: breads, flours, groats and pastas. The 'bread' category was wide as it contained sweet breads, crackers, ordinary breads etc., containing 12 products. 'Flours' and 'Groats' contain 3 products respectively and 'Pastas' include 5 products. The products consisted mainly of refined flours, though, whole grain products occurred as well.

The products were sent to the laboratory company Eurofins for analysis. All substances were analysed with LC-MS/MS and specific internal standard. Since trinexapac-ethyl converts into its acid form when in contact with water, both forms were analysed. The limit of quantification (LOQ) for the substances is presented in Table 6.

Table 6. The limit of quantification (LOQ) for the analysed substances

Substance	**LOQ [mg/kg]**
Chlormequat	<0.005
Ethephon	<0.020
Mepiquat	<0.005
Trinexapac (acid)	<0.0050
Trinexapac-ethyl	<0.0050

The information on the products (Table 7 & 8), concerning cereal content and origin was provided by the suppliers via Coop. In the cases where multiple origins are connected to a cereal ingredient, the certain batch presented in this thesis may derive from one or several of those countries.

4 Result

Residues of the substances were found in 12 out of 23 products (52%). All samples in which residues were detected are presented in Figure 9. The most frequently detected substance was chlormequat, in the range of 0.006-0.15 mg/kg. Trinexapac and mepiquat were found in two samples respectively. No residue of ethephon was found in any sample. The highest amount of chlormequat residues were found in 'Bread 1' (0.15 mg/kg) and 'Bread 7' (0.12 mg/kg). In 'Bread 1', also the highest amount of trinexapac (0.011 mg/kg) was detected. In 'Bread 5' the highest amount of mepiquat (0.14 mg/kg) was found, which was also the second highest amount of any substance residue. No residue was found in any of the groats. All residues in all products were however below the MRL for the corresponding grain types.

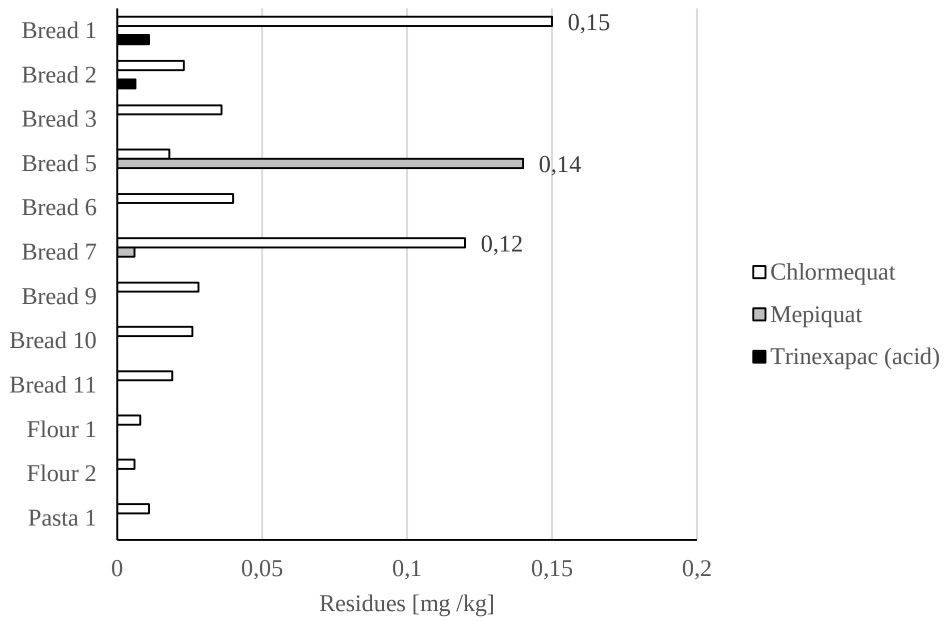

Figure 9. The amount of residues detected of the different substances in the products.

If assuming the substances only derived from the cereals, it is interesting to recalculate the amount of residue based on the cereal content as the products contain different amounts (Figure 10). When doing so, 'Bread 1, 5 & 7' still contained the most residues. However, the amount of mepiquat in the cereals in 'Bread 5' were in this case the highest (0.25 mg/kg). The recalculated residue amounts are still below the corresponding MRLs.

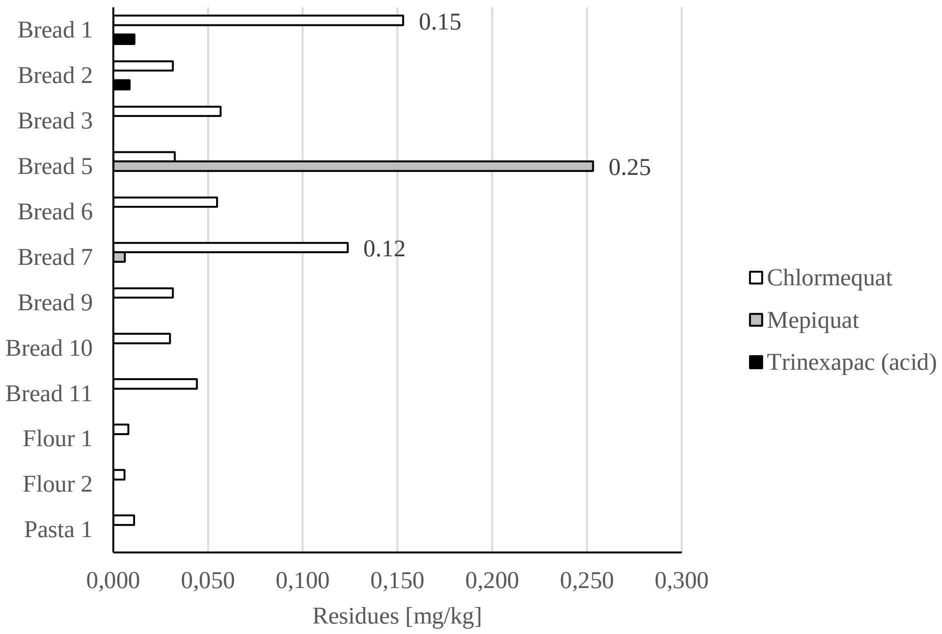

Figure 10. Residue values based on the cereal amount in the products.

4.1 Cereal Type and Origin

The cereal content and origin for all products is presented in Table 7 & 8. Wheat was the most occurring cereal. In 'Bread 1', the wheat content was 98% and contained the most chlormequat (0.15 mg/kg). 'Flour 2' contained the lowest amount of chlormequat residues (0,006 mg/kg) and consisted of 100% wheat flour. All products containing rye, also contained residues. 'Bread 7' contained 97% whole grain rye flour and had the second highest amount of chlormequat (0.12 mg/kg). Both products in which trinexapac was found, were based on wheat. None of the 'Groats' products, consisting of oats contained any residues. 'Flour 1 & 2' from Germany contained chlormequat residues, while 'Flour 3' from Sweden was free from detectable residues. 'Bread 5' which contained both rye and wheat deriving from Sweden, also contained the highest amount of residues, which was mepiquat.

Table 7. The products in which residues were found, the cereal content and origin

Product	Cereal content	Origin[1]
Bread 1	98% wheat flour	Germany
Bread 2*	73% wheat flour	France, Sweden, Austria, Netherlands, Belgium, Germany, Czech Republic, Romania, Hungary, Poland.
Bread 3*	55,8% wheat flour 2,5% wheat bran 2,8% rye flour 2,5% wheat groats	Wheat flour: Germany, Poland, France, Sweden, Denmark, Austria, Netherlands, Belgium, Romania. Rye flour: Germany, France
Bread 5	30% rye flour 23% wheat flour 2,3% wheat gluten	Sweden Sweden Sweden
Bread 6	73% wheat flour	Germany
Bread 7	97% whole grain rye four	Mainly Sweden, other origin may occur
Bread 9*	89% wheat flour	Italy, France, Germany, Hungary, Austria
Bread 10*	84% wheat flour 3% wheat fibres	Germany, Poland Germany
Bread 11*	43% wheat flour	Germany
Flour 1	60%wheat 40%rye	Germany Germany
Flour 2	100% wheat	Germany
Pasta 1	60% wheat flour 40% durum wheat	Latvia France, Germany

*Other cereals ≤1% occur

[1] In the cases where multiple origins are connected to a cereal ingredient, the certain batch may derive from one or several of those countries.

The cereals containing no residues (Table 8) were mainly produced by Sweden and Italy, although neither of the countries from which several products derived were all free from residues. The two products containing mepiquat derived both from Sweden. The rye in ‘Bread 7’ also derives from Sweden. All cereals deriving from Germany contained residues, as for ‘Bread 1’ with the highest amount of chlormequat.

Table 8. The products in which no residue of any substance were found, the cereal content and origin

Product	**Cereal content**	**Origin**[1]
Bread 4	59.9% Wheat flour	Sweden
Bread 8*	56% Wheat flour	Sweden
Bread 12	35% Wheat flour 1,7% Scalded wheat	Sweden Sweden
Groats 1	100% Oats	Sweden
Groats 2	100% Oats	Sweden
Groats 3	90% Oats 10% Wheat bran	Sweden Sweden
Flour 3	100% Wheat flour	Sweden
Pasta 2	100% Durum wheat	France, Russia, Kazakstan
Pasta 3	70% wheat flour 30% durum wheat	Italy Italy
Pasta 4	70% wheat flour 30% durum wheat	Italy Italy
Pasta 5	100% durum wheat	Italy

*Other cereals ≤1% occur

[1] In the cases where multiple origins are connected to a cereal ingredient, the certain batch may derive from one or several of those countries.

4.2 Maximum Consumption

Based on the acceptable daily intake (ADI) for chlormequat (0.04 mg/kg bw day) and mepiquat (0.2 mg/kg bw/day) it is possible to calculate the amount of product a person could eat without theoretically being exposed to an appreciable risk from the residues. If choosing the products containing the most residues (Bread 1, 5 & 7) and a person weighing 70 kg the following amount of products could be consumed, Table 9.

Table 9. The amount of products a person weighing 70 kg would have to eat daily to reach the acceptable daily intake (ADI)

Product	**Residue value [mg/kg]**	**Amount of product [kg/day]**
Bread 1	0.15 (chlormequat)	18.7
Bread 5	0.14 (mepiquat)	100
Bread 7	0.12 (chlormequat)	23.3

5 Discussion

As only one sample from each product was analysed, it is important to have in mind that the amount of residues can vary for each batch, the numbers only state the amount of residue in the certain sample and is not representative for the product. However, based on the current result, chlormequat was the most frequently detected PPP in the wheat and rye products, but no residues of PGR were found in the oats products, also, the MRL was not exceeded in any sample. Chlormequat was also the most frequently found PPP in cereals according to an Estonian study performed between 2008-2011 (Matt et al. 2013). In the EFSA Report on pesticide residues in food from 2014 in which wheat flour was analysed, chlormequat was the most frequently detected PPP (47.7%), although no samples exceeded the MRL. In the EFSA report from 2013, rye and oats were analysed, chlormequat was the most detected in both cereals (61.8% of oats and 40.3% of rye samples). The MRL was exceeded in 0.8% of the oats samples, and none of the rye samples. Mepiquat was also one of the most frequently found PPP in rye (16.8%), however, no samples exceeded the MRL.

In this thesis, 75% of the bread samples contained chlormequat in a range of 0.018-0.15 mg/kg. In a survey carried out in the United Kingdom, 41% in 2000 and 42% in 2001, of analysed bread samples contained chlormequat residues in a range of 0.05-0.2 mg/kg (LOQ=0.05) (Reynolds et al. 2004). Although the samples used in this thesis were too few to make a representative comparison, it may be stated that chlormequat is frequently found in cereal based foodstuffs and the range of residue detection was similar.

In previous studies, it has been stated that the chlormequat residue content is higher in the bran than in the endosperm (Granby & Vahl 2001; Reynolds et al. 2004). This means that the residue level should be higher in whole grain products than in refined flour products. In the two products that clearly contained the highest amount of chlormequat, 'Bread 7' consisted of 97% whole grain rye. However, the other products 'Bread 1', consisted of 98% refined wheat flour. As the samples in this thesis were few, it is difficult to draw conclusions.

The wheat in 'Bread 1' originated from Germany. All cereals deriving from Germany contained residues. This complies with the previously stated fact that Germany has the largest share of sold PGRs in the EU. Both products containing mepiquat derived from Sweden (Bread 5 & 7) also contained chlormequat. These two products also contained rye. As previously stated, the use of PGRs in rye has been accepted by law and the cereal industry for a long time in Sweden, it may have been expected to detect residues. As declared in Table 7 & 8, some products containing wheat may origin from numerous countries where Sweden is included. It is therefore uncertain to state that no wheat from Sweden was completely free from residues. However, in the products that consisted mainly of wheat and derived only from Sweden, no residues were found, even though corresponding PPPs for mepiquat, ethephon and trinexapac are allowed to be used on wheat in Sweden. 'Bread 5' differs from the other Swedish products as it contains a larger part of both wheat (25.3%) and rye (30%). The mepiquat residue in this product may derive from both cereals.

The low detection of PGRs in wheat in Sweden seems to correspond to the general attitude in the industry. As mentioned in section 2.11, the Swedish milling association, Lantmännen, Pågen, and The Absolut Company are generally against the use PGRs, especially in wheat. Even though the legal trend is going in the opposite direction, by recently broadening the use of BASF Cycocel containing chlormequat, to also be used on wheat, among other cereals. One can speculate that the sales of chlormequat may increase in the future, as demonstrated in Figure 4, the sales of trinexapac increased in 2012 when the usage terms of Moddus M broadened in 2011. However, as mentioned in chapter 2.11.1, if the use increased, the government might take action and prohibit the PPPs.

Although there was no detection of ethephon, but frequent detections of chlormequat in the products, one cannot exclusively base the findings on the use of PGRs. As stated in chapter 2.7, the substances have different chemical properties and therefore different decomposition properties. Although, the sales of chlormequat has been higher than the other substances (Figure 4).

It is important to have in mind that the substances may be approved to be used on other crops in agriculture and horticulture outside of the EU. If importing fruit and vegetables from third countries, one cannot exclude the presence of PGRs.

However, MRLs are set for other foodstuff as well, and regular sampling for analysis are carried out to make sure the products are safe to consume. Residues of chlormequat has been detected earlier in pears and table grapes, where it has been seen as a risk to vulnerable groups. Chlormequat is however no longer approved to be used on pear trees in the EU (EFSA 2009; EFSA 2010).

In the complex and extensive assessment by the European Commission and national authorities of the active substances and products, one may believe that the residues in the cereal products on their own pose no risk to the human health as it is below the corresponding maximum residue limits. However, the literature indicates a higher risk for the operators, handling the plant protection products, especially products containing chlormequat as an active substance (Nisse et al. 2015). The products in which most residues were detected (Table 9), a large amount needs to be consumed to exceed the acceptable daily intake (ADI). One can speculate that after consuming 18.7 kg bread per day, risks for other health complications may be just as great. In relation to the highest levels of mepiquat (1.4 mg/kg) formed in coffee beans during roasting (Wermann et al. 2014), the highest amount of mepiquat found in this thesis may be considered as low (0.14 mg/kg). Wermann et al. states that based on the coffee powder containing 1.4 mg/kg MQ, the daily intake of 7 cups would exceed only 0.2% of the ADI.

When reviewing other favourable effects of PGRs on cereals than to prevent lodging, such as increased yield, the literature points to different results for all substances. Generally, in the cases in which the yield increased it may be due to an indirect effect of the partitioning of dry matter from the stem into the grains instead. Of course, several factors influence the yield; such as the weather and fertilization (Rajala & Peltonenn-Sainio 2000). Therefore, to use these PPPs for other reasons than to prevent lodging may not be motivated.

Alternative methods to prevent lodging may be to use the preventional methods recommended by the Board of Agriculture, but also to use shorter and sturdier cultivars. In the assessment by the Board of Agriculture in 2012 on the proposal to prohibit PGRs, it was stated that the first prohibition in Sweden was expected to direct the Swedish cereal breeding to focus on the stem length and strength. However, the assumption tuned out not to match reality. Instead the Swedish cereal breeding has rapidly decreased and the priority in other countries has been on yield, quality and resistance properties. Cultivars with the mentioned properties may therefore not have a sufficient straw strength (Jordbruksverket 2012). One can speculate that the use of PGRs could be seen as a more available and guaranteed method, as lodging can result in loss of harvest and thereby a financial loss for the farmer.

To establish a product requirement, implying that no PGR residues shall be present in cereal products, may be difficult to achieve in the near future as the majority of products contained PGR residues. An extensive discussion with the current suppliers would be needed to investigate the supply of PGR-free cereals in the countries concerned and if it is logistically possible to segregate the raw materials. Traceability and a guarantee that the products are free from PGRs would be needed. Additionally, an investigation of the attitude towards these PGRs in other counties may be helpful when contracting new suppliers. As the PGR Imazaquin may be used on wheat in some countries, this substance should also be considered in the requirement. Perhaps, the suppliers could offer Premium-brands, similar to the concept of Lantmännen. If the supply of PGR free cereals is unavailable or insufficient, organic material is probably the only option, however, the price would increase and the concept of the brand may be distorted.

6 Conclusion

The residues in these certain products were below 10% of the maximum residue levels for the corresponding cereals, therefore, based on the assessments by the EU, the residues in the analysed products pose no risk to the consumer.

Based on the analysis result on these certain samples, Coop should avoid purchasing cereal products from Germany in general, and to purchase more wheat from Sweden and Italy instead, to limit the presence of PGRs as far as possible with their current suppliers. It may however, be difficult to avoid PGRs in rye.

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Legislation

Commission Directive 2010/2/EU of 27 January 2010 amending Council Directive 91/414/EEC as regards an extension of the use of the active substance chlormequat.

Commission Directive 2006/85/EC of 23 October 2006 amending Council directive 91/414/EEC to include fenamiphos and ethephon as active substances.

Commission Directive 2008/108/EC of 26 November 2008 amending Council Directive 91/414/EEC to include flutolanil, benfluralin, fluazinam, fuberidazole and mepiquat as active substances.

Commission Directive 2006/64/CE of 18 July 2006 amending Council directive 91/414/EEC to include clopyralid, cyprodinil, foseytl and trinexapac as active substances.

Commission Regulation (EU) No 540/2011 of 25 May 2011 implementing Regulation (EC) No 1107/2009 of the European Parliament and of the Council as regards the list of approved active substances.

European parliament and council EC No 396/2005 of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC

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9 Appendix

9.1 Popular scientific summary

Severe lodging of cereal crops due to heavy rains can cause serious problems in grain growth and quality, and is most common in rye due its substantially longer straw. Pesticides which reduce the straw height may be used to prevent this problem. Residues of some of these substances are however often detected in cereal products. To avoid a significant intake of pesticides, the food company Coop Sverige AB has therefore a desire to limit the possible presence of residues in the cereal products of their own brands. To make reasonable decisions regarding demands on suppliers and requirements on their products, an analysis to map the possible presence of residues in the products is needed, additionally, information on the certain substances are required.

In the European Union, the active substances that are to be used in pesticides must be assessed by the European Food Safety Authority and approved by the European Commission. However, the pesticide products only need to be approved on a member state level before they are allowed to be used. The assessment procedure of the substances is complex and extensive, as a lot of information and trails are required. If a substance is approved, numerous limit values are set as to acceptable exposure and what is acceptable for food to contain.

There are several pesticides used for straw height reduction in cereals in Sweden, however, there are only four active substances in total present in these pesticides: chlormequat, ethephon, mepiquat and trinexapac. Since all substances are approved by the Commission, they are considered not to have any harmful effects on human or animal health as residues in food products. The use of these kinds of pesticides has been debated for a long time in Sweden, and even though the substances are approved to be used on most cereals today, the use is still being debated in the cereal industry. Several important actors have introduced policies implying that these pesticides are not to be used at all, on certain cereals or in certain brands.

There were 23 cereal products sent for analysis of the 4 substances. The products included breads, flours, groats and pastas. Residues were found in 12 of these products. Chlormequat was the most detected residue, this complies with earlier studies where chlormequat is frequently found compared to the other substances. Mepiquat and trinexapac were detected in 2 products respectively, and no residues of ethephon were found in any sample. All cereals that originated from Germany contained residues, while the majority of the products originating from Sweden and Italy were free from residues. All products containing rye also contained residues. However, no residue exceeded the allowed levels for the corresponding cereal types in the products, therefore the residues in the analysed food poses no risk to the consumer.