(DOI): 10.5935/PAeT.V6.N1.13

This article is presented in English with abstracts in Spanish and Portuguese

Brazilian Journal of Applied Technology For Agricultural Science, Guarapuava-PR, v.6, n.1, p.105-114, 2013

Bibliographic Review

Sweet corn: Genetic aspects, agronomic and nutritional traits

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Abstract

Brazil, as a major producer of sweet corn common in the world, has a great potential for the production of sweet corn. This special type of maize can be divided into two groups, the group consisting of sweet gene amylose extender, dull1 and sugary whose characteristics change the type and amount of polysaccharides in endosperm and present smaller quantity of sweet corn starch when compared to common. The second group is the super sweet that has a high concentration of sugars in the endosperm at the expense of the production of starch, as well as the largest collection period. From a nutritional standpoint sweet corn has proven more demanding in soil fertility in maize common because of richness in sugars coupled to an intensive metabolism and a shorter cycle, moreover, both as to the common sweet corn, it is found that they are very demanding for N and K. The present study aims to conduct a literature review of the genetic aspects, agronomic traits and nutritional in sweet corn.

Key words: *Zea mays* L.; saccharata group; shrunken-2.

Milho doce: Aspectos genéticos, agronômicos e nutricionais

Resumo

O Brasil, como um dos maiores produtores de milho comum do mundo, possui um grande potencial para a produção de milho doce. Este tipo especial de milho pode ser dividido em dois grupos, o grupo doce composto pelos genes amilose extender, dull1 e sugary que têm como características alterarem o tipo e quantidade de polissacarídeos do endosperma e apresentarem menor quantidade de amido quando comparado ao milho comum. O segundo é o grupo super doce que apresenta grande concentração de açúcares no endosperma em detrimento da produção do amido, assim como o maior período de colheita. Do ponto de vista nutricional o milho doce têm se revelado mais exigente em fertilidade do solo em relação ao milho comum, devido a riqueza em açúcares, aliada a um intenso metabolismo e a um ciclo mais curto, além disso, tanto para o milho comum como para o milho doce, verifica-se que os mesmos são muito exigentes em N e K. O presente estudo tem por objetivo realizar uma revisão de literatura acerca dos aspectos genéticos, agronômicos e nutricionais na cultura do milho doce.

Palavras-chave: *Zea mays* L.; grupo saccharata; shrunken-2.

Maíz dulce: aspectos genéticos, agronómicos y nutricionales

Resumen

Brasil, como uno de los mayores productores de maíz común en el mundo, tiene un gran potencial para la producción de maíz dulce. Este tipo especial de maíz se puede dividir en dos grupos, el grupo dulce compuesto por los genes amilose extender, dull1 y sugary que tiene como características cambiar el tipo y la cantidad de polisacáridos presentes en el endospermo y presentar menor cantidad del almidón en comparación con el maíz común. El segundo grupo es el súper dulce que tiene una alta concentración de azúcares en el endospermo a expensas de la producción de almidón, así como un

Received in: 24/09/2012 Accepted for publication: 10/03/2013

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mayor período de cosecha. Desde un punto de vista nutricional maíz dulce ha demostrado ser más exigente en fertilidad del suelo que el maíz común, debido a la riqueza de azúcares, aliado a un intenso metabolismo y un ciclo más corto, además, tanto como para el maíz común como para el maíz dulce, está claro que son muy exigentes para el N y K. El presente estudio tiene como objetivo llevar a cabo una revisión de la literatura sobre las características genéticas, agronómicas y nutricionales del maíz dulce.

Palabras clave: *Zea mays* L., grupo saccharata; shrunken -2.

Introduction

The sweet corn (*Zea mays* L. saccharata group) belongs to the family Poaceae or Gramineae, tribe *Maydeae*, of the genus *Zea*, originating in the Central America and was domesticated in a period between 5000-8000 BC (ARAGÃO, 2002). It stands out over 250 cataloged breeds of the species *Zea mays* L. In which is considered as vegetable crop (TRACY, 2001). Its main uses as food are canned, by industrial process (PEREIRA FILHO and CRUZ, 2002) and the consumption "*in natura*" (OLIVEIRA JUNIOR et al., 2006). Additionally, after the harvest, the remaining vegetative parts of plants can be used for silage, which is destined for animal feed (TEIXEIRA et al., 2001).

For statistical purposes, any type of maize harvested and eaten before the physiologic maturation stage, still fresh, while the grains are soft and before all sugar is converted into starch, can be classified as sweet corn. Thus, according to information obtained by the Food and Agriculture Organization of the United Nations (FAO), in 2009, the global area cultivated with sweet corn was of 979,700 hectares and the global production was of 9,192,282 megagrams of ears, with prominence for the United States that produced 46% of this total.

Brazil, one of the largest producers of common maize in the world, also has a great potential for the production of sweet corn (BORDALLO et al., 2005). According to BARBIERI et al. (2005) this segment presents growth and the tendency is that it will be maintained, mainly due to the export and the increased used in family farming for its higher added value. As a resu1t, some companies, governmental and private (GAMA et al., 1983), have been developing breeding programs for production of sweet corn cultivars adapted to the Brazilian conditions (SCAPIM et al., 1995).

In this context, considering the lack of information, it is justified to perform the present study, which aims to conduct a literature review regarding the genetic, agronomical and nutritional aspects of the crop of sweet corn.

Sweet Corn

The crop of sweet corn is a activity financially rewarding due to the high unit price of the ears, which makes it a good alternative to economic exploitation in areas close to large urban centers and in small properties (PEREIRA FILHO, 2003). Furthermore, the vegetative part can be utilized for animal feed, such as hay or silage of high quality (STORCK et al. 1984).

In spite of the positive points, sweet corn generally presents low productivity, production problems in the offseason, lack of good cultivars for the consumption "*in natura*" (PARENTONI et al., 1990; GAMA et al., 1992), low resistance to pests and diseases (TRACY, 2001) and in addition, the percentage of germination is generally lower than in the common maize due to its lower starch content in relation to the other sugars in the seed (WATERS JUNIOR and BLANCHETTE 1983).

In the sweet corn the sugars crystallize inside the endosperm and during the dehydration occurs the separation between the pericarp and the aleurone, thus creating internal spaces that provide a wrinkled aspects to the seeds (DOUGLAS et al. 1993). As a consequence the pericarp becomes more fragile and more susceptible to physical damage and entry of pathogens (WATERS JUNIOR and BLANCHATTE, 1983; DOUGLAS et al. 1993).

It is known that the growing interest for this particular maize encouraged some seed companies to maintain genetic improvement programs that have resu1ted in greater numbers of commercial hybrids (GAMA et al., 1992; SCAPIM et al., 1995). In this manner, the study of management practices more suitable for these hybrids is of fundamental importance.

Genetic Aspects

The main characteristic of the sweet corn is to present at least one of the eight recessive mutant genes, which expression alters the composition of the endosperm of the grain (PARENTONI et al., 1990). The high contents of sugars of the sweet corn occur due the presence of the mutant alleles that block in the endosperm the conversion of sugars into starch, granting the sweet character of this type of maize (BARBIERI et al., 2005). These amendments are the resu1t of the action of recessive individual genes, or associated in double and triple combinations.

The mains responsible genes are the "shrunken-2" (*sh2*) located in the chromosome 3, "brittle" (*bt*), in the chromosome 5, "sugary enhancer" (*se*), "sugary" (*su*) and brittle-2" (*bt2*), all of them in the chromosome 4, the genes "dull" (*du*), in the chromosome 10 and "amylose extender" (*ae*), in the chromosome 5 (TRACY, 2001).

According with PARENTONI et al. (1990), the mutant alleles can be classified into two groups: sweet corn containing the gene sugary (*su*) and the super sweet corn containing the gene britle (*bt*), shrunken (*sh*) or sugary enhancer (*se*).

Group of the sweet: characterized by containing the genes amilose extender (*ae1*), *dull*1 (*du1*) and sugary (*su1*) which alter the type and quantity of polysaccharides of the endosperm (BOYER and SHANNON, 1984), and present a smaller quantity of starch when compared to the common maize.

The gene *su1* has as characteristic the increase of the concentration of polysaccharides soluble in water (PSA), which are characterized by presenting carbohydrates of branched chain, responsible by the structure and creamy texture of the grain (ARAGÃO, 2002), increasing this of 5 to 9% the content of sugar. Therefore, the gene *su1* is used in the simple form, or in combination with other mutant genes (BOYER and SHANNON, 1984). The increase in the level of polysaccharides soluble in water and in the endosperm arises from the fact that the sweet corn be a homozygous for the recessive gene (*su1*).

According to GARWOOD et al. (1976), the main component extracted of the fraction PSA is the phytoglycogen, which can represent up to 25% of the dry mass of the grain and is practically nonexistent in common maize grains (ARAGÃO, 2002). It is noteworthy that the phytoglycogen is a component of the highly branched carbonic, chain which accumulates in great quantities in the endosperm of the sweet corn (*su1*). It is more chained then the amylopectin, component of the maize with starchy endosperm.

According to this last author, the concentration of carbohydrates of the grains of sweet corn which contain the gene *su1* is practically the same as the normal grains. Such fact occurs due the continuous increase of the phytoglycogen contents in the endosperm.

The sweet corn hybrids with the gene *su1* normally present better vigor and germination of seeds when compared with the group of the super sweet. However, present shorter harvest period, due to a rapid conversion of sugar to starch (TRACY, 2001).

Group of the super sweet: the cultivars of this group are bearers of the genes brittle1 (*bt1*), brittle2 (*bt2*) and shrunken2 (*sh2*) in the recessive homozygous form (PARENTONI et al., 1990). These genes cause a severe blockage in the starch synthesis, which results in the accumulation of high contents of sugars in the endosperm of the grains and, therefore are called "super sweet" (ARAGÃO, 2002).

The super sweet corn is characterized by the great concentration of sugars (18 to 40%) in the endosperm in detriment of the production of starch (BOYER and SHANNON, 1984) at the stage of mature grains, which causes a decrease in the total carbohydrate content. Another advantage is the greater harvest period, since the loss of water of the grains is slower, due to the greater osmotic potential granted by the high concentration of sugars in the endosperm of the grains / seed (TRACY, 2001).

For the same authors: the disadvantages of the super sweet corn are: low accumulation of PSA and, consequently, non-pasty texture of the grains at the point of green corn, as occurs with the sugary and sugary enhancer mutants.The seeds of the super sweet are more fragile and light, and can easily suffer mechanical damages, which compromise the germination and rising of plants on the field. The seeds of this genotype are very susceptible to damping-off which is common to happen in pre or post rising, since the increase of the sugar content gets the plant more attractive to pathogens and soil pests.

Among the mutant genes, the *sh2*, *bt1* e *bt2* are the more used in the development of the commercial sugar corn, since the production of sugars in cultivars bearers of the gene *su* is smaller when compared with the others bearers of the genes *sh2* and *bt2*. These maintain high contents of sucrose even after the first cycles of the harvest, for consumption "*in natura*", beyond this, present the double of content of sugars, in relation to maize with the gene *su* and four to eight times the quantity of sugar in a grain from common maize.

Another beneficial characteristic is that the genotypes *sh2* present in average 30% more protein than the genotypes *su1.*

Agronomical aspects

In Brazil, the production of sweet corn is mainly focused for industrial processing, through contracts done between the industries of processing. Its utilization is diverse, being available in conservation (canned), frozen in the form of ears, in dehydrated grains, or even for consumption "*in natura*" (KWIATKOWSKI and CLEMENTE, 2007). In the case it has been harvested before pollination it can be used as "*baby corn*" or mini corn and, thus, after the harvest, the straw of the crop can be used for the production of silage (TEIXEIRA et al., 2001).

The harvest of sweet corn must be done when the ears are with 70 to 80% of humidity and preferably in the early morning hours, when the humidity of the air is high and temperature is low (PEREIRA FILHO, 2003; CANIATO et al., 2007). It has been verified that grains that present high contents of humidity have a decrease in the industrial productivity, result of the great number of ears at the stage "crystal" of "water bubble", which is only tolerated until the limit of 8% by the industry of conservation (PEREIRA FILHO and CRUZ, 2002).

The specie of the plant of sweet corn to field should present some attributes for better acceptance of the processing industry and/or consumption "*in natura*". For example, the possibility of the cultivation during the whole year, through the use of irrigation and staggered production; productivity of ears above 12 Mg ha^{-1}; cycle varying between 90 and 110 days, greater longevity of the period of harvest (5 to 8 days) (PEREIRA FILHO et al., 2003); uniformity of the plant height and size of the ears, characteristics these, that can be achieved by the use of simple hybrids, and must present also uniformity in the contents of humidity of the grains (69 to 75%), which grants better palatability of the product and maintenance of the flavor; as well as high grain yield per ear, and, absence of damage caused mainly by the corn ea worm (*Helicoverpa zea*) (FORNASIERI FILHO et al., 1988).

In order to attend both the interests of the processing industry as for the production for consumption "*in natura*", the sweet corn must present productivity above 30%, that is, for each 100 kg of husked ears, the productivity must be greater than 30 kg of canned grains, with ears above 15 cm of length and 3 cm of diameter (PEREIRA FILHO, 2003). The ears must present cylindrical shape with a clean and thin cob, dented and long grains with intense yellow or orange coloration (TEIXEIRA et al., 2001); more than 14 grain rows, which allows greater industrial productivity and balance between the number of straw and perfect protection of the ear (FORNASIERI FILHO et al., 1988), that is, layers of straw above 14 impair the industrial productivity and below 7 do not protect sufficiently, which enables the attack of pests and diseases(SAWAZAKI et al., 1990). Therefore, the texture of the grains must be uniform and with thin pericarp, of 45 to 50 microns, characteristics which grant greater softness to the grains (TEIXEIRA et al., 2001).

According with CANIATO et al. (2007), the consumer market of sweet corn became increasingly demanding in relation to product quality. The characteristics commonly used to describe the quality of sweet corn "*in natura*" include health, appearance, as well as compositional characteristics, which provide the maize characteristically flavor and scent (KWIATKOWSKI and CLEMENTE, 2007; KWIATKOWSKI et al., 2011).

From the compositional characteristics, it can be highlighted the concentration of starch, polysaccharides soluble in water, reducer sugars and sucrose, which varies according to the type of seed, weather conditions and close associates with the stage of maturation (MARCOS et al., 1999). These characteristics should be evaluated when the contents of humidity of the grains are between 70 and 80% for better recommendation to the producer and acceptance of the consumer market (CANIATO et al., 2007).

The chemical composition of the grains of the different types of sweet corn varies between themselves, for existing characteristics of each gene, specie and/or cultivar (TRACY, 2001). Despite this variation, the sweet corn is a product of high nutritional value, independent if the maize is of the type sweet or super sweet (Table 1)

The sweet corn differs from the common maize not for taxonomical characteristics, but by the high content of sugars and low content of starch (PEREIRA, 1987). In general, it is verified that in the common maize the value is around of 3% of sugar and 60 to 70% of starch. Therefore, the group of the sweet corn posses around 9 to 14% of sugar and between 30 to 35% of starch and, the maize of the super sweet group has around 25% of sugar and 15 to 25% of starch (SILVA and KARAN, 1994).

Table 1. Chemical composition of the sweet corn (su1) and of the super sweet (*bt1* e *sh2*).

Reference	Gene	Solids soluble (°Brix)	Proteins	Starch	Reducer Sugars	Total Sugars
			(%)			
PEREIRA (1987)	bt1	20.8	11.6	20.2	2.1	5.2
	su1	22.3	11.0	22.9	1.9	4.6
	su1	17.7	10.8	24.2	1.6	4.3
REIFSCHNEIDER et al. (1988)	su1	22.0	10.0	---	---	---
	su1	17.0	9.0	---	---	---
NELSON (1980)	su1	---	---	20.6	4,3	---
	sh2	---	---	17.4	8.3	---
SOUZA (2011)	sh2	---	---	16.0	---	27.3
	sh2	---	---	17.5	---	25.1
KWIATKOWSKI et al. (2011)	su1	---	11.7	26.3	3.7	8.4
OKUMURA (2012)	sh2	---	35.0	---	---	11.6

These differences in the composition of the grains occur at the phase of milky grains, that is, on green maize, which the grains of the sweet corn get tenderer and with higher quantity of sugars, in relation to the common green maize. These characteristics of the sweet corn differs of the common maize due to the sweet flavor, of the high nutritional value, better palatability of the grain and appearance of the ears, granting aptitude for human consumption, and thus receiving the classification of vegetable (TRACY, 2001).

It should, however, be evaluated the cultivars especially for the consumption of the maize "*in natura*", since there is still a great number of farmers that use for this purpose the same cultivars intended for the production of grains (PEREIRA FILHO and CRUZ, 2002). Actually, the recommendation of cultivars of maize those are appropriate for the consumption at the green phase has motivated the study of its chemical attributes, which can facilitate the choice of the same (CANIATO et al., 2007).

Researchers have been developing studies to modify the content of certain substances in the grains, since that the chemical composition can be modified through genetic manipulation (GAMA et al., 1983; PARENTONI et al., 1990). On the other hand, On the other hand, it should be emphasized that only in the last years is that the breeders have provided increased attention to these aspects (KWIATKOWSKI and CLEMENTE, 2007).

Modification in the contents of carbohydrates are of extreme importance, in occurrence of being biochemical constituents abundant in vegetables, which can represent up to 50 to 80% of total dry matter of these (CANIATO et al., 2007). The sweet corn, as consumption "*in natura*" as well as for processing, presents high contents of sugars, results of the action of the recessive individual genes or associated in double or triple combinations.

The starch represents the main carbohydrate of reserve in most of the vegetables, presenting granules with shape and sizes dependent on its botanical source, and composed of two types of macromolecules, the amylose and the amylopectin (TAIZ and ZEIGER, 2009). However, the sweet corn posses a low content of starch in the endosperm in face of the mutant alleles that alter the metabolic route of the formation of starch, in this way favoring the accumulation of sugars (BOYER and SHANNON, 1984; SILVA and KARAN, 1994). It is verified that in the content of starch, there is 32,6 to 25,0% of amylose and 67,4 to 75,0% of amylopectin, for the common maize and sweet corn, respectively (HEREDIA ZARATE and VIEIRA, 2003). It should the highlighted that the deposition of starch in the endospermof the grains increases with the evolution of the process of maturarion (CANIATO et al., 2004).

It is known that the sweet corn harvest must be done when most of the starch has not already accumulated, since the sweet flavor characteristic of the fresh product is due to the presence of sugars in the grains (CANIATO et al. 2007). In this manner, the lower the starch concentration, better the palatability of the product. In turn, the ideal proportion between sugars and starch basically depends on the type of preparation which is sent the ears (PARENTONI et al. 1990).

In relation to food proteins, these have, besides the nutritional function, sensory properties, especially of texture. In the sweet corn, the reduction in the accumulation of polysaccharide, mainly starch, leads to an increase in the content of proteins in the endosperm (PAES, 2006). According to LAUNDRY and MOUREAUX (1970) the proteins of the grain of maize can be classified in six fractions: albumin, globulin, zein, glutelin 1, glutelin 2 and glutelin 3. The zeins are proteins of the group of prolamins and are most abundant in normal maize grains, which can represent 45 to 60% of total protein of the endosperm (CAPOBIANGO et al. 2006).

The proteins of maize grains are deficient in two essential amino acids: the lysine and the tryptophan, which classifies it as of low nutritive quality (KWIATKOWSKI et al., 2011). There is, however, mutant lineages which contain the genes "opaque-2" and "floury" which reduce the synthesis of zeins and, consequently, increase the percentage of proteins rich in lysine and tryptophan in the endosperm (PAES, 2006).

Nutritional demands

The nutritional elements that most of the plants need to complete its cycle are: C, O, H (incorporated to the vegetable tissues from the absorption of H_2O by the roots and the incorporation of CO_2, by the photosynthetic processes); N, P, K (primary macronutrients); Ca, Mg, S (secondary macronutrients) and B, Cu, Fe, Mn, Mo, Zn and C1 (micronutrients) (MARSCHNER, 1995).

From a nutritional point of view, the sweet corn has been revealed itself as the most demanding in soil fertility, in relation to the common maize. The richness in sugars, with an intense metabolism and a shorter cycle can justify this greater demand in terms of soil fertility (PARENTONI et al., 1990).

The nutritional needs of the maize, as for any plant, are determined by the total quantities of nutrients absorbed during its cycle (FURLANI et al., 1977; DUARTE et al., 2003). This extraction will depend, however, of the productivity obtained and of the concentration of nutrients in the grains and in the straw (VON PINHO et al., 2009). Based on the quantities extracted, it can be estimated the quantities exported through harvest of the grains and the ones that may be returned to the soil through crop residues.

Differences in the demands and quantities of nutrients absorbed in function of cultivars, productivity, availability of nutrients and water, cultivation techniques and weather conditions were observed by different researchers (HANWAY, 1962) (table 2).With regard to the needs of nutrients of the sweet corn, until the present moment, few information are available, quoting the researches of MAGGIO (2006) and BORIN et al. (2010), presented in Table 3.

In a general way, as for common maize as for the sweet corn (tables 2 and 3), it is verified that the same are too demanding on N and K in comparison to the other macronutrients. This higher demand indicated the importance of N as for the crop of common maize (OKUMURA et al., 2011a) and sweet corn (OKUMURA, 2012).

It is necessary, thus, to maintain the fertility of the soil, seek to perform the restitution of the extracted elements, both the leached and lost nutrients by the process of erosion (SHARIFI and TAGHIZADEH, 2009; OKUMURA et al., 2011b).

Table 2. Productivity of grains and accumulation of macronutrients in the aerial part of cultivars of common maize obtained in works conducted in Brazil.

References		Primary macronutrients		
	Grains	N	P	K
	---------------------------- ($kg\ ha^{-1}$)	----------------------------		
FURLANI et al. (1977) [1]	6.800	111.5	14.6	127.2
HIROCE et al. (1989) [2]	4.900	135.7	22.5	86.2
DUARTE et al. (2003) [3]	7.700	204.0	25.0	162.0
VON PINHO et al. (2009) [4]	14.100	364.0	84.0	314.0
		Secondary macronutrients		
	Grains	Ca	Mg	S
	---------------------------- ($kg\ ha^{-1}$)	----------------------------		
FURLANI et al. (1977) [1]	6.800	37.4	14.9	57.8
HIROCE et al. (1989) [2]	4.900	20.6	22.5	12.7
DUARTE et al. (2003) [3]	7.700	24.0	41.0	11.0
VON PINHO et al. (2009) [4]	14.100	60.5	42.0	27.0

1 Average of two cultivars, population of 50.000 plants ha^{-1}, Campinas – SP; 2 Average of four cultivars, population of 50.000 plants ha^{-1}, Campinas – SP.

3 Average of five cultivars, population of 55.000 plants ha^{-1}, Palmital – SP; 4 Average of two cultivars, population of 60.000 plants ha^{-1}, Lavras – MG.

Table 3. Accumulation of macronutrients in the aerial part of the cultivars of super sweet corn (*sh2*) obtained in works conducted in Brazil

References	Gene	N	P	K	Ca	Mg	S
		------------------------------- (kg ha^{-1}) -----------------------------					
AGGIO (2006) [1]	sh2	395.0	75.0	403.0	43.7	32.2	32.2
BORIN et al. (2010) [2]	sh2	123.1	18.9	126.2	13.2	25.7	10.8

1 Population of 55.000 plants ha^{-1}, Itatiba – SP; 2 Population of 62.500 plants ha^{-1}, Jataí – GO.

According to MALAVOLTA (2006) the fertilization and maintenance should restitute to the soil the quantities of nutrient that the plants extracted, taking as base the information of the tables 2 and 3, giving priority the availability of macro and micronutrients extracted by the grains. The objective of this handling is to avoid the loss of fertility of the soil and/or become inefficient in a particular nutrient.

For the cultivation of sweet corn, PITTA et al., (1992) suggest pH between 6.0 to 7.0 especially in soils of low fertility, since this range of pH favors the increase the availability of nutrients of the soil solution to the plants, as well as reducing the phytotoxicity of aluminum (MARSCHNER, 1995).

Regarding to nutrition and fertilization of the sweet corn there are little information which can validate any specific recommendation, in consequence, FERREIRA (1993) recommends that when is aimed the commercial production of sweet corn that be used the same indication for the production of green maize and/or grains yield.

Final Consideration

The genes shrunken-2, brittle and brittle-2 are the most used for the production of seeds of commercial sweet corn, for presenting higher contents of sugars, both greater period of harvest in comparison to the bearers of the genes sugary enhancer, sugary, dull1 and amylose extender.

The sweet corn in more demanding in fertility of the soil in comparison to the common maize, on the other hand, the nutritional demands are similar for both, in which are especially demanding for nitrogen and potassium.

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