Review: on maize grain harvest mechanization and its influencing factors

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Abstract: Mechanically harvesting is important indicator of technology transformation in agricultural production, increase farm efficiency, income and productivity and solves the contradiction between labour shortage and maize production, but often increase the grain lost, ear lost and breakage percentage due to high grain moisture content at harvest which is the key problem of harvest mechanization in maize production. This paper reviewed relationship between the grain moisture content and its relation to grain filling, agronomy character and management, genetic character and environmental factor. The effect of moisture content on these factor and provide the possible way to increase the harvest mechanization also analyzed. The result provide a basis for increase maize mechanization harvest by selecting suitable varieties with the fast dehydration rate and adopt to the environmental condition. Improvement of maize varieties should done through the breading in concern of yield and quality, lodging resistance, fast dehydration rate and low moisture content at physical maturity.

Key words: Maize; grain mechanically harvest; grain; moisture content; influencing factors

0 Introduction

Most essential factor of agricultural development is mechanization on agricultural production leads to industrialization in agriculture. Improve techniques are included and practices in agricultural technologies that affect the final production of agricultural product [1]. Shahid et al. [2] reported that agricultural mechanization is a key mechanism to improve crop yield, decrease labour related cost in crop production and increase prosperity of farmer. Technology improvement and promotion for crops enclose new varieties and management regimes [3].

In China improvement of maize production has been increase with the introduction of new hybrids [4], but increase in maize yield is often accompanied by improves water and fertilizer conditions and extension growth period of the varieties, resulting higher grain moisture content and late maturation [5]. Late maturity of the maize is may be due to late in planting date, having the cool growing seasons, slow dry down rate, short growing season and early harvest; which finally increase the moisture content at harvest. Moisture content on grain and its effect led to the increase in grain loss rate, ear loss rate breaking rate as well as impurities rate at harvest [6]. High grain moisture content is related to the type of hybrid used in the specific ecological area and the duration of maturity of the hybrid and other management practices.

Physiological maturities of maize achieve around at 100 to 120 days at the kernel moisture content between 28 to 30% [7] or depending on the weather and cultivated genotypes. The grain moisture content at the physiological maturity makes grain harvest unfeasible, due to difficulties in threshing and more moisture and green part in the plants, which derive to various kinds of injuries in manipulation of grain. Generally, harvest operation is done at around 18 to 25% of moisture, to meet this range of moisture content natural drying (field drying) is adopted by many farmers [8]. Here we have put forward the fundamental and external factor influencing maize

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harvest mechanization.

1 Current situation on maize mechanization

Agricultural mechanization is the way of improving the farm labour productivity by using the agricultural machinery. It includes all types of power sources and mechanical supporting tools, human resources for agricultural production, from hand tools to computerized mechanical equipment. It reduces hard labour work, solve the problem of labour shortage and increase the production through timely operation and efficient use of available resources in agricultural production and also improve market access [9]. These can be operated manually, animals or by power engine. Thus it represent the changes of technology by which the acceptances of non-human sources of power to perform the agricultural operations. Agricultural mechanization can be divided into power and control intensive functions. Power intensive include field preparation, grinding, threshing and milling which is characterize as input of non-human sources of energy by replacing animals and human. Whereas the control intensive mechanized operations, weeding, planting, harvesting, winnowing, needed higher judgment of human mental effort in addition to energy [10]. But the grain harvesting can be considered of control and power intensive operation [11].

Mechanization in agricultural is an important to increase the productivity through the farmer's effort or to maintain net income and it also guided by changes in relative prices in particular cost of labour against cost of investment. It also increase yield of land per unit area, efficiency, farm income and per man productivity which solve the shortage of labour in agricultural production and lead to the agricultural commercialization by improving the agricultural technique and better uses of agricultural land. Agricultural production, mainly crop harvesting is still labour intensive processes. The main problem in the process of maize production is how to solve the contradiction with the labour shortage and need of labor amount.

Agricultural mechanization started in China from the beginning 50s' of 19th century. Mechanization is one of the important strategic targets of the Chinese government to build the modernized agricultural production. Rapid growth of the Chinese economy, mechanization of agricultural enters in China in a fast development orbit and has become essential component in development of agricultural mechanization of the world [12]. Sift of labour forces from agriculture to other industry made labour shortage in rural areas because of great reforms of rural industrial structure [13].

In resent year China machine access level increase rapidly and made great progress. The integrated mechanization rate of china reached 59.5% in 2014 which is nearly two third of the crop that are planted and harvest by mechanization. But, integrated mechanization rate is highest in wheat than maize and rice which is followed by 93.7%, 79.8% and 73.1% respectively [14]. The mechanical sowing rate of the maize is 84.1% in china but harvest account only for 51.6%, which is still lower than the average harvest percentage and has become the big problem of whole process maize mechanization production. The statistic data from 2004 to 2014 shows mechanized planting area increase substantially but the harvest rate grows with 8.6% annually [15] and still faces the problem. Target of agricultural mechanization of china to reach 70% in 2020 can be obtain with the fastest developing speed in mechanization of agricultural [16].

However, agricultural mechanization technology plays an important role in developing countries and it should be taken as essential input to agricultural [17]. The aim of agriculture mechanization input is to have a direct effect on production, productivity on a farms as well as quality life of people engaged in agriculture and labour productivity [18]. The increasing rate of

agribusiness and industrial production of maize product has increasing demand of maize production. To meet high demand of the maize for industrial production with cost effective in production and increasing the life stander of the people who are engaged in agricultural production and to solve the problem in labour shortage, mechanization in maize production is essential.

2 Problem of maize harvest mechanization in China

Maize mechanization has made a great progress in the world especially in the harvest level but china maize mechanization rate is lower than other developed countries which have a considerable gap, expert pointed out that the mechanical harvest is the direction of the maize mechanization. The harvest rate of the maize is lower than other major crops like rice and wheat in China which effect total maize production and has become the big problem of the whole process mechanization in maize production [19]. Main problem of maize mechanization harvest is grain moisture content; this is due to the different varieties use in production, production area, and agronomic character of maize and management practices with the technical adaptation of machine grain collection [20]. Although many varieties have been released in china recently, most of the varieties have problem such as slow dehydration, higher moisture content at physically maturity, difficulty in husk removing during the mechanical harvest and high rate of maize grain breakage [21] which is not be solved yet.

Moisture content in the maize kernel is an important factor in maize cultivation. Low moisture content provide many advantages like well perform the mechanical operation, it reduces the drying, storage cost after harvest and accordingly, reduces energy utilization. Many researcher suggested that the grain moisture content at the harvest can be controlled through dry-down rate of grain before and after physiological mature which is heritable trait, and it has a major variation among maize hybrids. The variation of grain drying rate is directly correlated with many agronomic traits of maize [22]. Oliveira et al. [23] has reported that seeds harvested with high moisture content are more susceptible to mechanical damage during harvest and husking caused mainly by machinery rotation of threshing cylinder and moisture content of maize seeds at harvest may affect the germination and vigor. Kernel breakage susceptibility depends on the varieties genotype [24]. Grain broken rate increase when the grain moisture is higher, which is the main maize quality problems for maize mechanized harvest in China [25]. Maize dehydration rate of the maize directly affects the moisture content of maize grain, and moisture content of the grain determined the softness and hardness of the maize grain.

3 Influence of moisture on maize grain harvesting mechanization

Maize harvesting is whole mechanized in developed countries where as in developing countries it is done manually till date. The kernel from the cob is removed from the mechanized system but manually harvest only can remove ear from the plant and should be shelled later stage. In both harvest situations, moisture content of kernel is very important because damage of kernel is mainly related to moisture content at harvest. If the moisture content at harvest is low the damage rate is also low [26]. Grain mechanical harvesting, shelling and drying are the result of change in physical quality. The peripheral damage of the maize grain like pericarp breaking and part around germs are the consequence of harvesting and shelling which facilities attack by insect and fungi, but on the other hand drying does not cause physical damage, if it is not done accurately like too rapid drying using high temperature it will led to formation of stress cracks,

discoloration and swollen that will affect effectiveness of dry milling and many other procedure [27].

The decisive factor influencing mechanical collection of grain is grain moisture, lead to grain crushing rate and increase the loss rate in mechanized harvest, [28,29] high grain moisture at harvest is one of the major problems in maize production, resulting in difficulties in harvesting, threshing, artificial drying, storage, transportation and processing [30,31] and prone to mildew [32]. High moisture content of grain also increases the cost of drying after harvest, which often causes maize growers and operators to suffer great economic losses and greatly reduce the economic benefits of maize production [33]. Excessive moisture content may lead to delays in harvesting time and may aggravate the susceptibility of maize ear to natural disasters such as disease and bird hazards [34, 35].

Grain moisture at harvest is one of the main properties that affect maize production, especially in the northern maize growing area [36] where the summer are short and winter are long. The current main problem in major maize varieties at physiological maturity in China is high moisture content of grain (grain moisture content more than 30%), slow grain dehydration characteristics. However, many other varieties also have problem like; after the maturity the stalk quality is poor, led to serious lodging, late grain dehydration and also often cause the machine grain damage, grain yield loss and other issues, limiting the further promotion of maize mechanically harvest. A survey shows that the current harvesting machinery in the harvest of grain, the most appropriate water should be maintained at 30%, preferably between 18% -25% [37]. To promote the mechanized harvest of maize and to improve the quality of maize by screening a large number of summer maize varieties with low water content, fast dehydration rate, high yield and good performance to combine harvester at harvesting stage.

3.1 Effect of moisture content and its relationship on grain filling on maize harvest mechanization

Relations of moisture content in kernel are good indicator of developmental process during grain filling [38, 39]. Decrease in moisture content of the maize grain is actually the process of grain filling. The changes happened both in water content and dry-matter of the maize ear in the period of silking to harvest. The dry-matter increase in the kernels determines grain-yield; this process is normally examined in term of rate and duration [40]. According to several authors water loss from kernels during grain filling is mainly is an exchange between dry matter and water [41-43]. If it happens, the common pattern of dry-matter accumulation should be fairly similar regardless of genotype or location when expressed on a grain moisture basis, and hence, maize kernels should reach Physiological maturity at on the same grain moisture [42, 43].

After Physiological maturity the grain moisture is determined by the loss of water from the kernels, and the rate of drying process [44, 45]. Thus, Physiological maturity is defined as the time of achievement of maximum grain dry-weight. The last stage is indicated by a layer of cells at the base of the kernel that dies and turns black, forming a barrier (or black layer) between the kernel

and the rest of the plant and is considered to be physiological maturity at this period moisture loss is highly dependent on the kernel, ear and husk structure, the ear placement on the plant [46, 45], and weather conditions such as air temperature and relative humidity.

Water relation of the kernel plays an important role in controlling the period of the grain filling. This period is controlled by relationship between kernel moisture and biomass enlargement, which is determines by the time of kernel reach critical percentage of water content (i.e. Moisture content is measured on a fresh weight) at mean time plant biomass accumulation stop. The period at which this critical percentage of water content in gain can be affected by the period of net water uptake of kernel stops (i.e., water content reached at maximum), else with the relationship between moisture loss and biomass deposition after maximum moisture content is attained [47]. Wang et al. [48] found that the grain filling and dehydration process determines the rate of grain moisture content at harvest. The moisture content in maize grain at harvesting is determined by the rate of grain filling, water content during physiological maturation, and physiological maturation to grain dehydration rate during harvesting. Grain filling period is important for maize yield and quality, and a characteristic of grain filling is closely related to its yield [49]. The physiological water content of grain and yield of maize and its affect is determined by grain filling duration and rate.

Thus, grain moisture content at physiological maturity is affected by the grain filling processes of maize. Screening of maize varieties with the fast grain filling rate is one of the key issues to solve problem of maize harvest mechanization.

3.2 Effect of temperature on maize harvest mechanization

Climatic factor have great influence in agriculture production. Changes on global climate have foremost result on Maize yields and food supply. Climate changeability especially in temperature, rainfall, sunshine hour and humidity has a direct, regular adverse, effect on yield and quantity of agricultural production [50]. Solar radiations have directly linked on crop growth, any decreases cause reduction in agricultural productivity appreciably. The accompanied expand within minimum temperatures will increase preservation of respiration use concerning the crops or accordingly further reduces net growth followed by productivity stability [51]. The occurrence over excessive climate unevenness as much may also keep characterized by an unlimited dry duration and strong rainfall spell coinciding with the indispensable stages on maize growth or development which may lead to decreased maize yields or enormous maize losses.

Climate variability also affects the various grain processes, activities and maize yield. The risk related along climate variability concerning maize production of globally depends mainly on the growth stage of the maize plants so the weather aberration occurs [52]. When the temperature decreased and increased toward the maturity of the plant, the biological and seed yield decreased. The cultivars which remained because of longer duration among the area produced, higher seed weight so, in contrast in accordance with the cultivars as remained for shorter period of time [53]. Hence, the temperature is important factor in maize production.

A large number of studies have indicated that light, temperature, precipitation and other climatic condition also have impact on the grain moisture content of maize. The main factor influencing grain damages is temperature. But, the maize grains respire during the storage of grains and are biologically active. They might lose weight due to respiration at the time of stored in the field and harvested with moisture content less than 20 percentages [54, 55]. The removal of grain with low moisture content from the field promotes mechanical injure at harvest. Those damages might favor the occurrence of insects and fungal diseases during grain storage [56, 57]. Whereas, high moisture content in the grain lead to the maximum breakage or injury at harvest. Thus, grain harvest should be done in accurate time frame to reduce the losses at harvest.

Now days the mechanized harvest system (combine harvester) not only remove the ear from the plant but it remove grain from the cob. In this situation maize harvest is mainly done in the range of 18 to 24 percentage of moisture content. The damage occur during the harvesting operation is mainly due to the grain moisture content. Most of the study shows less harvest damage is obtain by less moisture content at harvest. Climate is also one of the most important factors in agricultural production which have direct affects on growth and development of crops, grain filling process and dehydration rate. The effect of climatic factor and its affect on grain moisture content and dehydration rate of maize different cultivars in different area and in accordance with various management practices.

3.3 Genetic factor on maize harvest mechanization

Impact of grain moisture at the harvest is versatile with the types of varieties which have genetic difference and morphological characters of maize [58]. The rate of dehydration of seed after the physiological maturity of maize decide differences in water content and dehydration rate of seed at harvest, and it is mainly additive effect in inheritance, which was first time discovered by Miller et al.[59]. The physiological maturity and grain dehydration rate between the varieties where significantly different which was confirmed by Purdy and Crane, Nass and Crane and Hillson and Penny [60-62] in their research work and this differences can be inherited. Grain physical quality also differs among maize hybrid along with rate of kernel breakage [63, 64] and kernel exhibiting stress crack [64]. Bauer and Cater [63] also reported the white endosperm maize varieties generally have late maturation, when harvested; the grain water content was high.

According to Sárvári and Futó [65,66], for some hybrids early sowing leads to an outstanding increase in yield and to lower grain moisture content at harvest and improve production efficiency. They recommend a variety-specific technology which adapts the sowing date to the hybrids in coordination with other production factors. Troyer and Ambrose [67] and other studies found that hard grain type than the horse-type hybrid seed have faster dehydration rate, but Li Yanjie [68] and other studies suggest that the horse tooth type have dehydration faster than hard-type hybrids. This difference may be related to the diversity of varieties used in different countries, environment condition and others agronomic practices. Jiang Yanxi et al. [69] pointed out that the field natural dehydration rate and the performance of grain moisture content at harvest have extremely

significant negative correlation. But, bracts length, grain width, and the moisture content of grain at harvest was extremely significant positive correlation; for the low harvest moisture content of maize varieties.

To meet the target of grain mechanically harvest we should focus our study on selecting the maize varieties which have the good performance on natural dehydration rate (i.e. field drying) and less kernel breakage percentage at harvest.

3.4 Effect of agronomic character of maize on grain moisture content and harvest mechanization

Agronomic characters such as husk thickness, length, plant height, ear height, seed type, earliness of maturity or late maturity etc. of maize hybrid widely affect the grain dehydration rate and grain moisture content. The differ in grain yield, drying rate, duration to maturity, stand ability, and pests and diseases resist are depend on maize hybrids. Zuber [70] had find out that maize husk thickness is one of the important factors affecting the rate of maize grain dehydration in his study, thinner bracts more conducive to maize grain dehydration. The less numbers of loose short husks was favorable for fast grain drying because the movement of air was limited by husks around the grains [46]. Loose husks on the maize ear are conductive for fast drying of the cob and ear in compare to normal and tied husks that have same drying rate of cob and ear which was reported by Hicks et al. [71]. Whereas, Crane et al.[72] examined the husk and shank characteristics and found that size or shape of the ear do not appear to be most important factors related with differing rate of drying along with trait of the maize and recommended that fast drying rate of maize was associated with the pericarp permeability. Kiesselbach [73] had pointed out husks protected the grain from the possibility damage by changing temperature and also delay drying rate of maize grain after maturity.

The shape and structure of the individual component of the maize have some effect on maize hardness. Hunter et al.[74] and other studies have found that hard grain type maize compared to the tooth type, hard grain type have fast grain dehydration rate. It was subsequently reported that maize varieties with higher grain water content were mostly late-maturing and had late maturing white endosperm maize with high water content at harvest. Zuber [70] reported that maize grain with the white endosperm have high moisture content then yellow and suggested that maize grain having white endosperm where late maturity than that of yellow endosperm, and ear height was significantly higher for the late maturity in his study. He also pointed out that late maturating varieties have high moisture content and yield.

Eyherabide et al.[75] found that the higher the ear height, the higher the water content of grains and the longer the time of loose grain, the higher the water content of grain. Miller et al. [59] has discovered that the late maturing verities of maize have high moisture content at harvest then the early maturity. Mathre et al. [76] found that the water content of maize was affected by ripeness of ear, ear diameter and grain number, and had a great influence. Hadi et al.[77] study show that moisture content of cob in early maturity varieties have similar to kernel whereas late

mature varieties which have high moisture content at harvest have high water content of cob. Zhang Liguo et al. [78] study shows that the ear diameter, ear row number, grain width and embryo weight / endosperm weight and maize physiological maturation rate of grain dehydration after direct path coefficient is positive, 100-grain weight, ear length, embryo accounted for grain volume ratio and the direct path coefficient of grain dehydration rate was negatively correlated with peel thickness and physiological maturity of maize. In order to obtain maize with fast dehydration rate, maize hybrids with short grain coarseness, larger grain width, thin peel and 100-grain weight, less, thin and loose husk genotype should be selected.

3.5 Effect of agronomic management on grain moisture content and harvest mechanization

The management practices like different planting time, planting density, different plant spacing configuration and other factors, will affect the maturity and test weight [79]. Crop yield is the important element on crop production. The trend on practicing high density of maize varieties to obtain high yield is a key factor on maize production, which emphasize on adaption of high density planting to improve yield [80, 81]. Song Fengbin et al. [82] showed that row spacing at 55 to 60 cm was most favorable for high yield, while Gao et al. [83] suggested that 50 cm and 70 cm spacing were most favorable for crop photosynthesis and yield formation. But Nelsen [84] had reported that when the row width is decrease from 76 to 38 it increases lodging. Other researcher have also pointed out that, when increases in plant density result in thinner maize stem that increase lodging risk and led to reduction on yield [85]. So, higher plant density widely depends on environment [86] and varieties [87]. Wu Jingfeng [88] study pointed out that the main factors affecting the maturity of maize is temperature, to make the selection of maize hybrids, in good cultivation and management conditions to ensure normal grain maturity, grain moisture contain and stable production.

The maize varieties and density relation with the grain moisture is depend on the varieties relative maturity. Grain moisture contain of early maturity varieties decrease with the density increase. But, the late maturity varieties had less time for field-dry to reach the physiological maturity. So, the moisture content of grain is higher across all plant density [89]. Ma Jing et al.[90] reported, that each species has a suitable close planting interval, for example, the suitable density range of XY335 was 60,000 ~ 75,000 plants/ha, and the moisture content decreased from 19.6% to 18.3% when harvested from 60,000 plants/ha compared with 75,000 plants/ha. The lower density was reduced by 1.3% moisture content, and also reduces the risk of lodging caused by increased density. Whereas delay in harvest time after the physiological maturity it will increase lodged percentage that reduces the actual grain yield for some varieties [91]. Imholte and Carter [92] and Russelle et al. [93] had find that late sowing reduced the grain yield and increased the grain moisture content at harvest. The effect of sowing date on the yield of spring maize in the North China Plain was obvious, in which the number of grains per ear was greatly affected, and the yield was limited. This affected the grain number per ear, and ultimately limits the yield increase [94]. The suitable varieties and cultivation technique are essential for adoption of maize mechanization

in short growing season (summer maize season) in China to meet the target of full mechanization.

4 Strategies for improving maize harvest mechanization

Form the preoperative of the history actual condition of maize mechanization of China and developed country is the trend of times. Mechanization in agricultural has been seen as the important revolution in most part of the world and contribute greatly to meet the food demand for growing population of world by increasing productivity of food crops and other agricultural production [95]. The realization of maize mechanization harvest can improve the comprehensive production capacity of maize, which has an irreplaceable strategic important for ensuring national food security. The food scarcity problem of many counties has been solved by agricultural mechanization. The mechanization of maize harvest also accelerate the objective need of land circulation and the appropriate scale of operation, realize the land management and intensive development of production and operation which is the trend of development of maize industry, and mechanical harvest of maize is also a heavy link in maize production in short period of time which protect food security of China. Agricultural Mechanization has made low input of the labour forces in production. For an instance, in USA only about 3 percentage populations are engaged in farming, thousands of people can feed by one individual farmer; one family can handle up to 1200 hectares of farmland in USA [96] because of agricultural mechanization. This example shows that where there is the shortage of labour forces agricultural mechanization is most important entity. To solve the problem of labour shortage in farming China should develop full mechanization on agricultural production even though agricultural mechanization is higher than other developing countries.

From the view of the current problems in the process of maize mechanical harvesting, we should take active measures in the future to promote the mechanization. In the prospect in mechanical problem, the relevant government department of agricultural and machinery manufactures companies should carried out various forms of cooperation and innovation, to increase scientific research strength and develop better quality of maize harvester to improve work efficiency of machine. In the view of current maize varieties use in china many of them don't well adapt to meet the mechanization harvesting of grain. Breeders should adjust breeding goal with consideration of yield and quality, lodging resistance, agronomic characters of high density and fast dehydration rate. Even though they are some relatively suitable maize varieties for mechanical harvest but these species in the field is not perfect still, the well adaptability varieties should be improve, and the selection of varieties should be continue with different agronomic management practices for future development in maize mechanization. Development of maize mechanization is necessary in China to protect the food security, to lift up the living stander of farmers and to full fill the gap of labour shortage in agricultural production and to build up the national economic.

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玉米籽粒机械收获及其影响因素研究综述

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摘要：机械收获是农业生产技术革新的重要标志，其提高了农业生产效率、收益和生产力，解决了劳动力短缺与玉米生产发展的矛盾，但也往往由于玉米收获期籽粒水分含量高而增加了落粒、落穗损失和籽粒破碎率，这是玉米生产中影响籽粒机械收获的关键问题。本文综述了玉米籽粒含水率与籽粒灌浆、农艺性状及管理、遗传性状及环境因子的关系，同时也分析了籽粒水分含量对这些因素的影响，以及提高籽粒机械化收获水平的可能途径。分析结果认为选择脱水速度快、适应栽培环境条件的适宜品种是提高玉米籽粒机械化收获的基础。玉米品种的改良应选择产量高和品质优良、抗倒伏性强、脱水速度快、生理成熟期水分含量低等方面进行。

关键词：玉米；籽粒机械收获；籽粒；水分含量；影响因素

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