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# The mathematical characteristics on ideal wheat stem structure in late growth period

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## ABSTRACT

In this paper we study the ideal stem structure for the wheat in late growth period. By means of experiment and data verification, it is demonstrated that the length of each section of the wheat ideal stem structure composes of the generalized Fibonacci sequence: (1) in the hard-dough stage, the mass ratio of the circular tube and rod is 0.5, the ratio of the outer and inner diameter is $\sqrt{2}$; (2) the ratio of the height of the center of gravity and stem (including ears) length is the golden section 0.618. The results not only can be used as breeders indicate a clear breeding goal, but also can provide the algorithm theory to the computer numerical simulation.

## KEYWORDS

The generalized fibonacci sequence; Golden section; Ideal wheat stem structure; Center of gravity; Late growth period.

## INTRODUCTION

With the improvement of the quality of the seed and the scientific of the management on the farm, the increase of the wheat's panicle weight makes the load of the stem increase, and lodging of the wheat occurs. The production of wheat stem lodging is an important reason. Therefore, to cultivate the high-yield, ultra high-yield wheat, it is necessary to study the ideal wheat stem structure (different height can reach the highest yield, the best lodging resistance of wheat stem structure), and in order to achieve the computer simulated breeding must have tallied with the actual situation of the mathematical model and practical algorithm to support.

As we known, the Fibonacci sequence and the golden section appear in biological settings in nature[1-6], such as branching in trees, arrangement of leaves on a stem, the fruitlets of a pineapple, the flowering of artichoke, an uncurling fern and the arrangement of a pine cone. In addition, numerous poorly substantiated claims of Fibonacci numbers or golden sections in nature are found in popular sources, e.g., relating to the breeding of rabbits, the seeds on a sunflower, the spirals of shells, and the curve of waves. The Fibonacci numbers are also found in the family tree of honeybees. So in this paper first we understand the Fibonacci sequence and the golden section and then analysis of wheat stem structure to find its mathematical characteristics.

## FIBONACCI SEQUENCE AND GOLDEN SECTION

The Fibonacci sequence is an integer sequence, its each number is the sum of its front adjacent two numbers of the sequence, With the increase of the sequence, the adjacent two ratio is infinite tends to the golden section ratio -- 1.68 or 0.618. As we known the golden section, also called the golden ratio, is a certain mathematical proportions on each part in one thing. It means put the whole into tow part, and the ratio of the larger and smaller is equal to 1 : 0.618 or 1.618: 1, the larger part is the 0.618 of the whole. 0.618 is recognized as the most aesthetic number. The golden section has metaphor a "golden section" because it's very precious as the gold. The Fibonacci sequence is also a numbering mode by the Nature, the rule of the Fibonacci sequence and the golden section is ubiquitous in the Nature[3]. From plants to animals, from microscopic to macroscopic, the magical Fibonacci sequence patterns and the golden ratio are filled everywhere.

Scientists find that: only in the Fibonacci sequence of this digital arrangement condition, plant leaves, can maximize using sunlight for photosynthesis; it means to the flower to spend as much as possible to show themselves to attract insects for pollination; it would mean to the seed as much as possible to maximize the dense arrangement, to ensure of reproduction and growth. Plants are particularly fond of the Fibonacci sequence, that is the inevitable result of evolution of the survival of the fittest in the natural selection of[4], because the most stable structures are inherently follow similar to the Fibonacci sequence of the form. The researchers Shipman says, this relationship will minimize the energy, but he also estimated, similar sequences may also occur in the human biology[5].

The Fibonacci sequence and the golden section is still full of mystery, because the Nature is magic everywhere. How the Fibonacci numbers and the golden ratio do the ideal wheat stem structure contains? In order to solve this problem we come to understand the generalized Fibonacci sequence.

## THE GENERALIZED FIBONACCI SEQUENCE

1) the definition of the generalized Fibonacci sequence: any sequence, if from third term, any number are the sum of front adjacent two numbers, is called the generalized Fibonacci sequence[6].

For example, the Lucas sequence: 1, 3, 4, 7, 11, 18,...... It is a kind of important generalized Fibonacci sequence.

2) the property theorem of the generalized Fibonacci sequence.

THEOREM 1 Suppose in the sequence $\{a_n\}, a_n \neq 0 \; (n \geq 3)$, the sequence is the generalized Fibonacci sequence, the necessary and sufficient condition is

$$(a_n + a_{n+1}) / a_{n+2} = 1, (n \in z_+).$$

PROOF $(\Rightarrow)$ Using the definition of the generalized Fibonacci sequence $a_n + a_{n+1} = a_{n+2} \; (n \in z_+)$, and in the sequence $\{a_n\}, a_n \neq 0 \; (n \geq 3),$ obviously we have $(a_n + a_{n+1}) / a_{n+2} = 1, (n \in z_+).$

$(\Leftarrow)$ Suppose $(a_n + a_{n+1}) / a_{n+2} = 1, (n \in z_+).$ Therefore, we obtain

$$a_n + a_{n+1} = a_{n+2} \; (n \in z_+) \; .$$

It means that $\{a_n\}$ is the generalized Fibonacci sequence.

Using the knowledge of the generalized Fibonacci sequence, we study the wheat stem structure. We know, the node number of the wheat stem is 4, 5 or 6, more than 90% varieties of the same species or more than 90% single stems are 5 nodes, while the 5 is a Fibonacci number.

## THE IDEAL WHEAT STEM STRUCTURE

The ideal wheat stem structure should make it has the best lodging resistance and the best yield. on this basis, the wheat stem height, each section length, thickness, wall thickness, height of center of gravity and even stem density should meet how relations or requirements. We study 12 species, 556 single stem in 3 years e.g.the Bainong AK 58, the Xinmai 208, Zhoumai 18 and so on, and the relevant materials, and we find the ideal single stem of wheat should have some common mathematical characteristics.

**The determination of the wheat stem (not including the length of pike)**

When you pick up a single wheat and look closely, you'll find out the wheat stems from base to spike the section length increases gradually, what kind of rule does the wheat stems have? Does it conform to the generalized Fibonacci sequence arrangement forms or not? In order to verify this result, we put the wheat stem length of each section as a five element array, using the generalized Fibonacci sequence property theorem, validating to the single stems wheat on different varieties. it was found the ratio of the base fifth section length and the sum of the base third and forth section length, the ratio of the base forth section length and the sum of the base second and third section length, its value is in mostly 0.8 ~ 1.2, the average values are 1.01 and 1.06, and the average value of the ratio of the base third section length and the sum of the base first and second section length is 0.72.

The specific method is as follows:

First,the abnormal data are Eliminated, and we define

$$Q_1 - 1.5R_1, Q_3 + 1.5R_1$$

are the data's lower and upper intercept point respectively (where $Q_3, Q_1, R_1$ is the lower and upper quartile and quartile deviation respectively). The data which is greater than the upper intercept point is the large value, and the data which is smaller than the lower intercept point is the small value. They are all regarded as the abnormal data.

When the population distribution is the normal distribution $N(a, \sigma^2)$, , the data's lower and upper intercept point in theory is respectively

$$\xi_1 - 1.5r_1 = a - 2.698\sigma,\ \xi_{0.75} + 1.5\sigma = a + 2.698\sigma..$$

The probability that the data drop out the lower and upper intercept point is 0.00698,that is the ratio of the abnormal data is the 0.00698 for the data of bigger capacity *n*.

Then, use the Excel to analyze the data and draw the histogram.

For the five section wheat, respectively analyze the data of the $(a_1 + a_2)/a_3$, $(a_2 + a_3)/a_4$, $(a_3 + a_4)/a_5$ named the first column, the second column and the third column and draw the histogram respectively as follow:

**TABLE 1 : The statistics result of the first column for the five section wheat**

| Statistic | |
|---|---|
| Average value | 1.34 |
| Standard deviation | 0.31 |
| Variance | 0.09 |
| Minimum value | 0.70 |
| Maximum value | 2.16 |
| Observation number | 167 |
| Degree of confidence (97.5%) | 0.05 |

**TABLE 2 : The statistics result of the second column for the five section wheat**

| Statistic | |
|---|---|
| Average value | 1.08 |
| Standard deviation | 0.15 |
| Variance | 0.02 |
| Minimum value | 0.75 |
| Maximum value | 1.46 |
| Observation number | 167 |
| Degree of confidence (97.5%) | 0.03 |

**TABLE 3 : The statistics result of the third column for the five section wheat**

| Statistic | |
|---|---|
| Average value | 0.97 |
| Standard deviation | 0.13 |
| Variance | 0.02 |
| Minimum value | 0.70 |
| Maximum value | 1.31 |
| Observation number | 167 |
| Degree of confidence (97.5%) | 0.02 |

For the six section wheat, respectively analyze the data of the

$(a_1 + a_2)/a_3$, $(a_2 + a_3)/a_4$, $(a_3 + a_4)/a_5$, $(a_4 + a_5)/a_6$

named the first column, the second column, the third column and the forth column and draw the histogram respectively as follow:

**TABLE 4 : The statistics result of the first column for the six section wheat**

| Statistic | |
|---|---|
| Average value | 1.18 |
| Standard deviation | 0.26 |
| Variance | 0.07 |
| Minimum value | 0.68 |
| Maximum value | 1.94 |
| Observation number | 49 |
| Degree of confidence (97.5%) | 0.09 |

**TABLE 5 : The statistics result of the second column for the six section wheat**

| Statistic | |
|---|---|
| Average value | 1.27 |
| Standard deviation | 0.19 |
| Variance | 0.04 |
| Minimum value | 0.81 |
| Maximum value | 1.73 |
| Observation number | 49 |
| Degree of confidence (97.5%) | 0.06 |

**TABLE 6 : The statistics result of the third column for the six section wheat**

| Statistic | |
|---|---|
| Average value | 1.20 |
| Standard deviation | 0.23 |
| Variance | 0.05 |
| Minimum value | 0.79 |
| Maximum value | 1.69 |
| Observation number | 49 |
| Degree of confidence (97.5%) | 0.08 |

**TABLE 7 : The statistics result of the forth column for the six section wheat**

| Statistic | |
|---|---|
| Average value | 0.94 |
| Standard deviation | 0.10 |
| Variance | 0.01 |
| Minimum value | 0.75 |
| Maximum value | 1.19 |
| Observation number | 49 |
| Degree of confidence (97.5%) | 0.03 |

From the above TABLES and histograms, we know the data present the normal distribution, and the average value is close to 1. Through the hypothesis testing of the normal population mean, we get that for the five section wheat the average value of each column is respectively 1.30, 1.06,0.99, and for the six section wheat the average value of each column is respectively 1.11,1.22,1.14,0.96.

Finally, we compare to this conclusion and the conclusion in reference[5]:

$\frac{l_{i+1}}{l_i + l_{i+1}} \approx 0.618$, where $i = 1,2,3,4,$ $l_i$ denote the length of the section i.and through the test of hypothesis we find the wheat stem from base second section the section length is more consistent with the generalized Fibonacci structure, and base section 1 and base section 2 structure is more consistent with the reference[7] conclusion. To Analyze of the reasons, we believe that this is because the wheat stem base section directly connected with root, directly leads to it has the different physiological effects with other sections, on the other hand, the measurement error is easily caused when we measured. Therefore, when we known the length of base section1 and the stem length, we can calculate the ideal stalk stem length (excluding the spike length ). Thus, further validates our conjecture: wheat stem sections of desired length should constitute a generalized Fibonacci sequence, which is consistent with the Nature of the growth rule.

**The determination of wheat stem diameter and the mass**

In the paper[8] according to analysis of the material mechanics theory the best ratio of the inner and outer diameter of the circular tube is 0.7, and under the conditions that the circular tube and rod diameter is the same, the pipe mass only is round rod mass $1/2$, but the rigidity of section is round rod $3/4$ times.

First we put this conclusion on wheat stem sections of inner and outer diameter ratio is validated, it was found from the blossom stage to the ripening stage the ratio of the inner and outer diameter of the wheat stem sections become bigger, and fluctuation range mostly in the 0.4 to 0.78, and in the ripening stage of wheat varieties the lodging resistance is better the ratio of the inner and outer diameter is more close to 0.7.

Second, assuming the same variety of wheat at the same time in the same stem material density, we put the wheat as the same density hollow round tube and solid round bar. To test the ratio of mass of circular tube and rod, we test their material volume ratio, test results shows from blossom to the ripening stage the mass ratio of circular tube and rod is between 0.38 and 0.57. And in ripening stage of wheat varieties the lodging resistance is better, and the mass ratio is more close to 0.5. Therefore, the mass ratio of circular tube and rod of ideal wheat stem in ripening stage should be 0.5.

**The determination of center of gravity height of wheat stem**

Since the golden section is in nature everywhere, natural wheat is no exception. Much of the literature shows that the center of gravity height of wheat stem should not exceed the $2/3$ of the stem height (including spike ). Through the literature and data validation we find that from blossom to ripening stage wheat stem (including spike ) the height of center of gravity is from low to high, and the ripening stage the lodging resistance is better, the ratio of the height of to the wheat varieties the center of gravity and stem length (including spike) is the more close to 0.618 ($< 2/3$). But it's uncertain that removing the spike, the ratio of height of center of gravity and stem length (including spike ) is close to 0.382 (stem (including spike ) the other golden point ), or the ratio the spike stem height of center of gravity and stem length (not including spike ) is close to 0.382 (stem (not including spike ) the other gold section points ), and this conclusion still need further verification.

## CONCLUSION AND DISCUSSION

The results show that, in the late growth period (from the blossom stage started) the ideal structure of wheat stem should have such characteristics:

(1) the length of the section from the base date form a generalized Fibonacci sequence;

(2) in the ripening stage stem ratio of the inner and outer diameter should be 0.7, the mass of the stem sections is the half of the mass of the rod within the same density of the material;

(3) in the ripening stage the ratio of the height of the center of gravity and stem (including spike ) length is the golden section 0.618.

The results of this study to determine the different height of the single stem of wheat can reach the best production and best lodging resistance and provide a theoretical basis, while using the mass ratio of the circular pipe and rod may also determine a single stem height, panicle weight with different varieties and different density material single stem diameter and wall thickness. This study not only for wheat seed breeding workers designate specific breeding goal, at the same time as the wheat seed breeding of scientific, modernization provide practical algorithm design and implementation possibility. However, the ideal wheat stem structure on the parameters is not fully defined, such as for the different stem height, how long should the ideal wheat stem base section 1 or base section second or under spike section 1 be? There is no conclusive; blossom stage ideal wheat stem is the center of gravity in the stem of another golden section 0.382 still need further verification; what kind of the rule do the ideal wheat stem, leaf area, leaf arrangement, the angle of leaf and stem have? It is not very clear. And so these also engaged in wheat research personnel and experts further study.

The results of this study are the crystallization of observed, conjecture and verification, still need relevant personnel further extensive data validation.

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