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Seed Productivity of Winter Wheat Depending on Sowing Dates and Seeding Rates

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Abstract

This article describes the formation of seed yields and seed quality depending on the timing of sowing and seeding rates. On average, over three years, seed yields significantly decreased when sown at late sowing dates compared to the optimal date of September 25. The influence of the "sowing time" factor on seed yield was the largest and amounted to 86.6%, while the influence of the "seeding rate" factor was insignificant and amounted to only 4.3%. It was found that the germination energy and germination rate of seeds did not change significantly depending on the sowing date and seeding rate of winter wheat: when sown at the optimal time of September 25 with a seeding rate of 3 mln/ha, the germination energy was 96%, germination rate was 96%, and when sown later on October 5, these indicators were the same, and when sown on October 10, they were 92 and 95%, respectively. Depending on the seeding rates, the yield of winter wheat varied, but no significant difference was found within each sowing period. Seed quality – germination energy and germination rate – did not change significantly depending on the sowing date and seeding rate of winter wheat.

Keywords

Yield; Seeds; Germination energy; Germination; Seeding Rates; Sowing Dates; Weight of 1000 seeds

Introduction

Ukraine is one of the leading countries in the global grain market with export potential exceeding 40 million tons. As one of the world's leading grain exporters, the country will play a globally significant role in providing food and grain raw materials to an ever-growing population. Therefore, the strategic objective of Ukraine's agricultural sector remains to increase the productivity of winter wheat, the key crop for national farming. Modern varieties and high quality of seed play a crucial role in this task (Morgun and Rybalka, 2017). The yield and quality of wheat seeds are formed during their cultivation, where both the genetic potential of the variety and soil, climatic and agro-technological conditions play an important role (Zhemela *et al.*, 2020), including sowing dates and seeding rates. Global warming observed over the past 25-30 years in Ukraine and the associated recurrence of droughts in autumn lead to changes in the timing of the autumn vegetation of winter crops, the ability to fully tilling in autumn, and necessitate research to determine the effectiveness of early optimal and late sowing dates of winter wheat and their sowing rates with the obligatory study of the effectiveness of integrated crop protection and the impact of this agricultural measure on the yield and sowing qualities of seeds of winter wheat varieties of different intensity (Zadontsev and Bondarenko, 1969). Therefore, the study of technologies for growing varieties of a new ecotype in order to increase their productivity and stabilize grain and seed production in modern agro-climatic conditions is quite relevant.

Review of Literature

Studies have shown that weather conditions, varietal characteristics and cultivation techniques are the main factors influencing the growth, development and productivity of winter wheat (Linina and Ruza, 2018; Mostipan *et al.*, 2021). In particular, an important element of winter wheat seed cultivation technology is sowing at the optimum time, which affects the entire life cycle of crop development, including seed germination conditions, seed germination simultaneous, uniformity of plant development, and simultaneous seed maturation. Pacanoski and Mehmeti (2020) found that changing the sowing dates can have a significant impact on the growth and development of the crop and its yield. At early sowing dates, plants develop a large vegetative mass, bush heavily, as a result of overgrowth, they use reserve substances intensively and become less resistant to adverse conditions, their winter hardiness decreases, they are more damaged by pests and diseases, and crops are weedier and can sprout. At later dates, they take longer to germinate, do not have time to open up in the fall, develop a sufficient root system and aboveground mass. There is no consensus on the resistance of late-sowing plants to unfavorable wintering conditions; it is believed that the highest winter hardiness is formed in plants that form 2 shoots by the end of the autumn growing season (Tkachuk, 2020). Late sowing in almost all areas of crop cultivation always leads to lower yields (Tkachuk and Tymoshchuk, 2020). Deviations in the timing of winter wheat sowing (early or late) lead to yield losses and a decrease in gross grain harvest by up to 10% on average (Pochkolina, Kohut and Serhieiev, 2023). Under the influence of sowing dates, changes in yield properties can occur, which depends on a certain shift in the interphase period of earing-ripening, which may coincide with certain weather changes for the better or worse for the formation (Korkhova, Smirnova and Drobitko, 2022). With climate change, the timing of sowing winter wheat cannot be optimal for all times, but only a certain range can be determined for specific soil and climatic zones (Nikitenko and Kovtun, 2021; Sandhu *et al.*, 2020). Among the elements of technology that affect the yield, yield of conditioned seeds and their multiplication factor, an important role is played by seeding rates (Voloshchuk, 2020), which ensures the appropriate plant density. Seeding rates also change, and are constantly reviewed and refined, taking into account the quality of the seed, improvements in crop cultivation technology and existing soil and climatic conditions (Morgun and Logvinenko, 1995). Given the persistent climate change and insufficient study of the influence of sowing dates on the yield and quality of winter wheat seeds under conditions of unstable moisture in the Right-Bank Forest-Steppe of Ukraine, the research is relevant and of great practical importance. The aim of this study was to evaluate changes in the timing and seeding rate of winter wheat seeds on the formation of yield and improvement of seed quality.

Methodology

The research program envisages determining the effect of sowing dates and seeding rates of winter wheat seeds on the yield and quality of seeds. Field and laboratory experiments were conducted at the experimental farm of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine during 2018-2023. Experiments were conducted with medium-ripening varieties Astarta, Zolotovolosa, Favoritka, Khurtovina and medium early-ripening varieties Smuglyanka, Sonechko, Natalka and Limarivna. The scheme of the experiment provides for sowing at the optimal time – September 25 and later on October 5 and on October 10 with seeding rates of 3, 4, 5 and 6 million units/ha of germinating seeds. The research was carried out with winter wheat varieties developed by the Institute of Plant Physiology and Genetics. Harvest accounting was carried out by continuous threshing of plants from each plot with a Sampo-Rosenlew SR 3085 selection combine. The weight of 1000 seeds were measured by an electronic balance. The number of germinated seeds was determined in a thermostat on a moistened substrate - filter paper at a germination temperature of 20º C. Germination energy was calculated on day 4, and germination rate on day 8. The weight of 1000 seeds was determined from two samples of 500 seeds in each replication. Statistical processing of experimental data was carried out by the methods of variance analysis according to the Fisher method using the computer programs (Ermantraut, Prysiazhniuk and Shevchenko, 2007; Fisher, 2006).

The soils of the research farm are predominantly light grey, podzolised, light loamy with a low humus content of 1.6-1.7%, with a slightly acidic soil solution reaction of pH 5.5-5.8, alkaline hydrolysed nitrogen of 100-120 mg/kg, mobile phosphorus of 90-100 mg/kg and exchangeable potassium of 70-80 mg/kg. The soil density in the equilibrium state is 1.16-1.25 g/cm^2, the moisture content of stability and wilting is 10.8%. In terms of temperature conditions, the years of research during the growing season of winter wheat were close to 0.2-4.4° C or higher than the long-term average, especially during the period of sowing and germination, which indicates sufficient heat supply to the crop plants. The warmest periods for plant growth and development were May, summer months and September, which were characterised by high temperatures. In terms of moisture supply, the growing season during the years of research was difficult, with significant deviations from typical weather conditions, which led to a decrease in the intensity of growth and development of winter wheat.

Results

On average, over three years, the seed yield significantly decreased when sown at later sowing dates compared to the optimal date of September 25 (Figure 1).

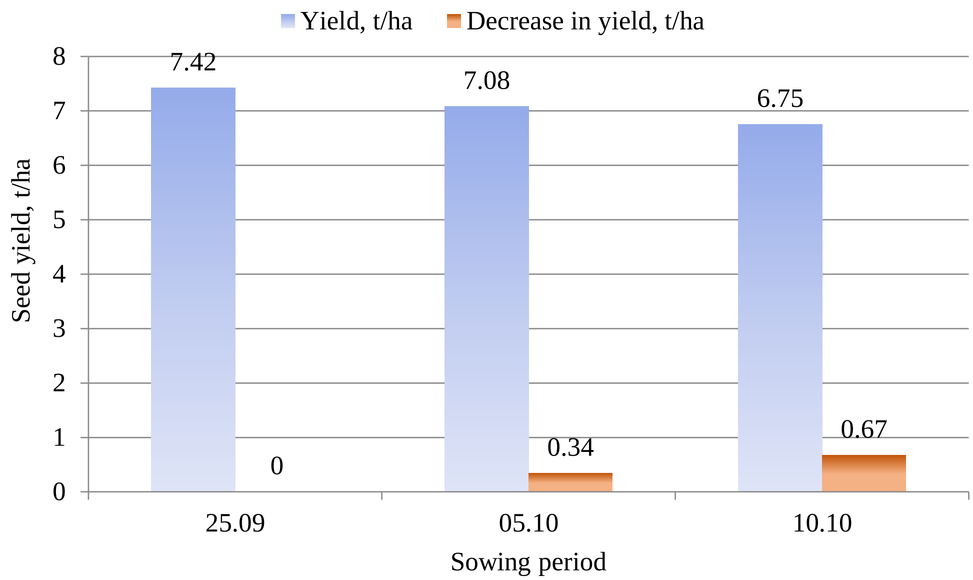

Figure 1: Winter wheat seed yield depending on the sowing date (average for 2018-2023)

When sown on October 5, the yield of winter wheat seeds decreased by 0.34 t/ha compared to the optimal yield, and when sown on October 10 it decreased by 0.67 t/ha. At the last date of sowing wheat (10 October), the seed yield significantly decreased not only compared to the optimal date, but also to the sowing on October 5 it decreased by 0.33 t/ha. Depending on the seeding rate, the yield varied, but no significant difference was found within each sowing period. When sowing at the optimal time, the seed yield was 7.47 t/ha at a seeding rate of 3 mln/ha, and 7.46 t/ha at 5 mln/ha ($LSD_{05\ \text{seeding rate}}$ = 0.04 t/ha), and only at a seeding rate of 6 mln/ha did the yield significantly decrease by 0.16 t/ha (Table 1).

A similar dependence was observed for sowing at a later date, i.e. October 5. At the same time, no such dependence was found for sowing at the latest date. A significantly lower yield was obtained at a seeding rate of 3 mln/ha – 6.64 t/ha, and at higher seeding rates it was 0.08-0.18 t/ha higher.

The analysis of the factors that influenced seed yields showed that the influence of the ‘sowing time’ factor was the largest and amounted to 86.6%, while the influence of the “seeding rate” factor was insignificant and amounted to only 4.3% (Figure 2). The impact of other factors and their interaction was also insignificant.

Numerous studies quoted in this article have shown that the germination energy and seed germination rate did not significantly change depending on the sowing time and seeding rate of winter wheat (Table 2). Thus, when sown at the optimal time on September 25 with a seeding rate of 3 mln/ha, the germination energy was 96%, germination rate was 96%; and when sown later on October 5, these indicators were the same, and when sown on October 10, they were 92 and 95%, respectively. At other seeding rates, a similar dependence was observed.

Table 1: Winter wheat seed yield depending on cultivation practices (average for 2018-2023)

Variant		*Seed yield, t/ha*
sowing period	*seeding rate, mln/ha*	
September 25	3	7.47
	4	7.45
	5	7.46
	6	7.31
October 5	3	6.92
	4	7.09
	5	70.9
	6	7.23
October 10	3	6.64
	4	6.72
	5	6.82
	6	6.81
$LSD_{05\ gen.}$		0.07
$LSD_{05\ sowing\ period}$		0.04
$LSD_{05\ seeding\ rate}$		0.04

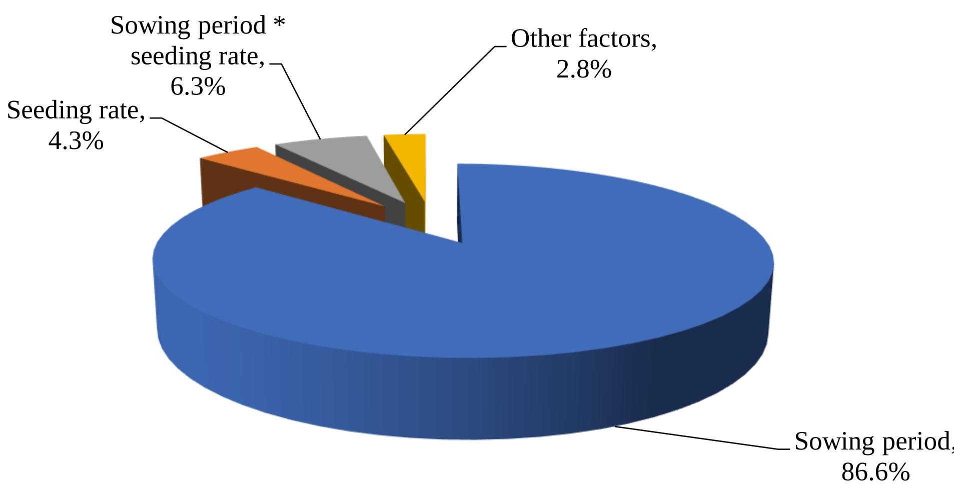

Figure 2: Factors influence on winter wheat seed yield (average for 2018-2023)

The weight of 1000 seeds is a genetically determined trait of each variety, which changes its parameters under the influence of growing conditions within insignificant limits, but its value is influenced by both sowing time and seeding rates. Depending on the sowing time, the weight of 1000 seeds was significantly higher at the optimal time compared to later ones. Thus, during sowing on October 5 at seeding rates of 4-6 mln/ha, the weight of 1000 seeds was 0.7-2.1 g less compared to the optimal sowing date ($LSD_{05\ sowing\ date}$ = 0.46 g). When sowing on October 10, this indicator was significantly lower at all seeding

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rates compared to the optimal sowing date. Seeding rates also influenced the weight of 1000 seeds, but there was no natural and significant decrease or increase in this indicator at late sowing dates with an increase in the seeding rate.

Thus, during sowing on October 5, at a seeding rate of 3 mln/ha, the weight of 1000 seeds was 49.8 g, the same as at a seeding rate of 6 mln/ha. Similar results were obtained for sowing at the latest date of October 10. Only at the optimal sowing date – September 25 – a natural and reliable decrease in the weight of 1000 seeds with an increase in the seeding rate was found. If at a seeding rate of 3 mln/ha the weight of 1000 seeds was 49.6 g, then at a seeding rate of 4-6 mln/ha, it decreased by 0.3, 1.8 and 1.9 g, respectively (LSD_{05} seeding rate = 0.54 g).

Table 2: Quality of winter wheat seeds depending on cultivation practices (average for 2018-2023)

Variant		*Seed quality*		
sowing period	*seeding rate, mln/ha*	*weight 1000 pcs, g*	*germination energy, %*	*germination rate, %*
September 25	3	49.6	95	96
	4	49.3	94	95
	5	47.8	94	95
	6	47.7	93	95
October 5	3	49.8	95	96
	4	50.0	93	95
	5	49.6	93	95
	6	49.8	95	95
October 10	3	50.1	92	95
	4	50.2	94	96
	5	50.1	93	95
	6	50.5	94	95
$LSD_{05\ gen.}$		0.93	2.0	2.2
$LSD_{05\ sowing\ period}$		0.46	1.5	1.6
$LSD_{05\ seeding\ rate}$		0.54	1.6	1.7

The analysis of factors that influenced the weight of 1000 seeds showed that the largest influence was the factor “sowing time”, which amounted to 54.3%, the influence of the factor “seeding rate” was less – 18.0%. The influence of the interaction of these factors was lower and amounted to 15.9% (Figure 3).

Correlation and regression analysis of the data showed an average inverse linear correlation between seed yield and weight of 1000 seeds. The correlation coefficient is R= -0.69. The location of the points on the diagrams indicates that with increasing seed yield, the weight of 1000 seeds decreases (Figure 4).

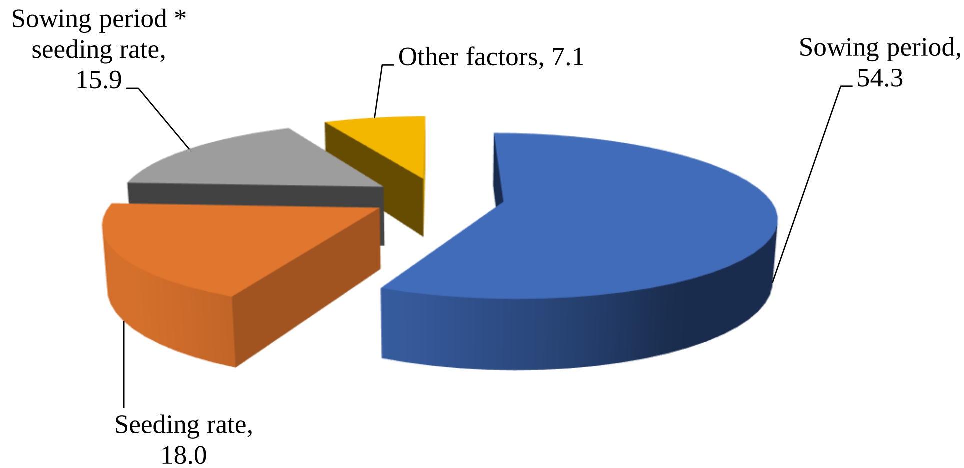

Figure 3: Factors affecting the weight of 1000 seeds (average for 2018-2023)

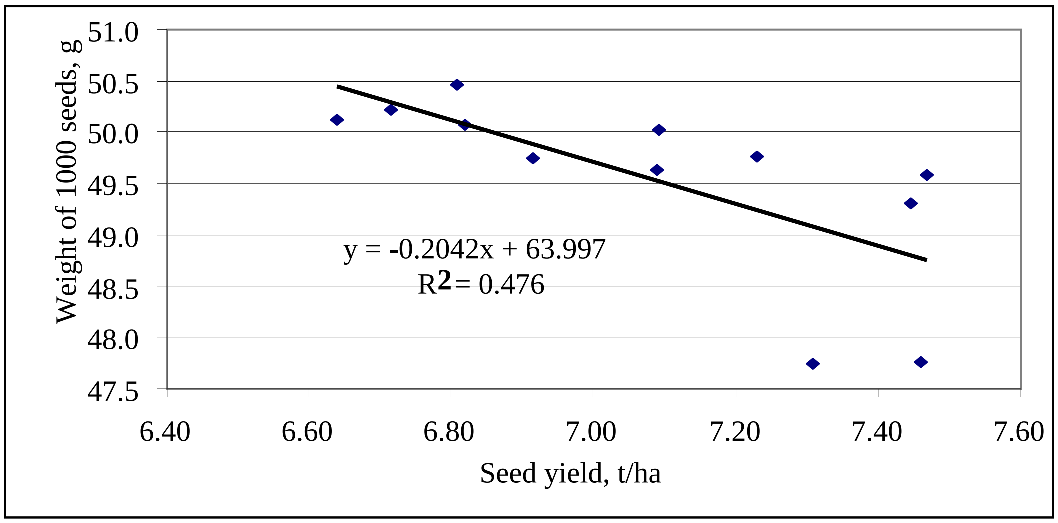

Figure 4: Dependence of 1000 seeds weight on seed yield (average for 2018-2023)

The dependence between these values is linear, with an average correlation. A regression equation describing this dependence was constructed: y = 0.2042x+63.997, with the value of the approximation reliability (coefficient of determination) being 0.0476.

Discussion

Timely sowing of grain crops is the main way to increase their yields, as sowing at the right time allows crops to reach their full yield potential (Meleha *et al.*, 2020). Researches have shown that wheat phenology has a strong correlation with sowing dates, as different sowing dates differ in terms of average growing season temperature and precipitation amounts (Aslam *et al.*, 2017; Klepeckas *et al.*, 2020; Sadras and Monzon, 2006). The results showed a 1% decrease in grain yield with each day of delay in sowing date. These results can be explained by the inhibition of crop growth, yield components, biomass production, etc. (Shah, Coulter, Ye, and Wu, 2020). Studies have shown that late sowing of wheat leads to poorer yields, even in years with optimal weather conditions (Tester and Langridge, 2010). Delayed sowing of winter wheat can lead to reduced seed germination and tillering ability due to lower temperatures during the growing season (Borras-Gelonch *et al.*, 2012; Dreccer *et al.*, 2013). Under such conditions, the flowering time of plants is shifted, which can further lead to accelerated reproductive development of plants and reduced grain filling (Bailey-Serres *et al.*, 2019; Shah *et al.*, 2020).

The results of the modelling carried out by Klepeckas and others showed that delaying the sowing rows can significantly reduce the rate of tiller growth. They found that winter wheat grew 232 (tillers m^{-2}) less with each week of delayed sowing in the autumn before wintering (Klepeckas *et al.*, 2020).

Meleha *et al.* (2020) have found that earlier sowing dates have a positive impact on winter wheat yields and quality compared to later sowing dates. They investigated the interaction between planting dates and planting methods and found that the interaction between planting dates and planting methods affected plant height, yield and seed quality only slightly, except for grain yield and 1000 grain weight in the first season and number of grains per ear in the second season of cultivation. The highest grain yield of 7752.5, 6970 kg-ha^{-1} was obtained by sowing wheat in the bedding on 20 November, and the lowest by sowing wheat in the bed at late sowing dates (Meleha *et al.*, 2020).

The results presented in this article are in full agreement with those obtained by other researchers. It was found that when winter wheat was sown at a later date, the yield significantly decreased. Thus, when sown on October 5, the yield decreased by 4.6%, and on 10 October – by 9.0%, compared to the optimal sowing date of 25 September.

There is an opinion that increasing the seeding rate can potentially increase the number of fertile tillers and other components of the winter wheat crop at late sowing (Shah *et al.*, 2020). Optimal seeding rate is a key management element for an efficient wheat yield (Arif *et al.*, 2017). It was found that in order to obtain a high yield of wheat grain with high quality, it is necessary to use precise seeding rates for different varieties, since an increase in the amount of seed can increase production costs without increasing grain yield (Rafique *et al.*, 2010).

This research has shown that by increasing the sowing rate to 6 million/ha at the optimal time of 25 September, the yield of winter wheat was 1.4-1.6 t/ha lower compared to lower sowing rates. However, with an increase in the seeding rate at a later date, the crop yield increased. Thus, when sowing winter wheat at a rate of 6 million/ha on 5 October, the yield was 1.4-3.1 t/ha higher, and when sowing on 10 October, it was 0.9-1.7 t/ha higher than at lower seeding rates. Thus, it was found out that it is expedient to increase the seeding rate of winter wheat during late sowing and inexpedient to increase it in the optimal time.

Conclusion

Sowing in late terms significantly reduced seed yields by 0.34 t/ha (sown on October 5) and 0.68 t/ha (sown on October 10) compared to the optimal date of September 25. Depending on the seeding rates, the yield of winter wheat varied, but no significant difference was found within each sowing period. The influence of the «sowing time» factor on seed yield was the largest and amounted to 86.6%, while the «seeding rate» factor was insignificant and amounted to only 4.3%. It was found that the germination energy and germination rate of seeds did not change significantly depending on the sowing date and seeding rate of winter wheat: when sown at the optimal time of September 25 with a seeding rate of 3 mln/ha, the germination energy was 96%, germination rate was 96%, and when sown later on October 5, these indicators were the same, and when sown on October 10, they were 92 and 95%, respectively.

The weight of 1000 seeds is a genetically determined trait of each variety, which changes its parameters under the influence of growing conditions within insignificant limits, but its value was influenced by both sowing dates and seeding rates. It was significantly higher at the optimal time compared to the later ones.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*
Conceived and designed the research or analysis	Yes	Yes	No
Collected the data	No	Yes	No
Contributed to data analysis & interpretation	No	Yes	No
Wrote the article/paper	No	Yes	Yes
Critical revision of the article/paper	Yes	Yes	No
Editing of the article/paper	No	Yes	Yes
Supervision	Yes	No	Yes
Project Administration	No	Yes	Yes
Funding Acquisition	Yes	Yes	No
Overall Contribution Proportion	35	45	20

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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