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Machine Learning Prediction of Anxiety Symptoms in Pregnant Women Based on Pregnancy-Specific Stress, Social Support, and Health Literacy

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A B S T R A C T

Objective: The present study aimed to develop and evaluate machine learning models for predicting anxiety symptoms among pregnant women based on pregnancy-specific stress, social support, and health literacy and to determine the relative importance of these predictors in identifying women at risk for elevated anxiety during pregnancy.

Methods and Materials: This applied cross-sectional predictive study was conducted among 384 pregnant women attending prenatal care centers and obstetric clinics in Tehran. Participants were selected through multistage convenience sampling and completed a demographic questionnaire, the Beck Anxiety Inventory, a Pregnancy-Specific Stress Questionnaire, the Multidimensional Scale of Perceived Social Support, and the Health Literacy for Iranian Adults Questionnaire. Following data preprocessing and descriptive analyses, machine learning techniques were employed to predict anxiety symptoms. The dataset was divided into training and testing subsets, and several supervised learning algorithms, including Logistic Regression, Support Vector Machine, K-Nearest Neighbors, Decision Tree, Random Forest, Gradient Boosting, and Extreme Gradient Boosting (XGBoost), were developed and evaluated using cross-validation procedures. Model performance was assessed using accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC). Feature importance analyses were conducted to identify the relative contribution of predictor variables.

Findings: Correlation analyses revealed a significant positive relationship between pregnancy-specific stress and anxiety symptoms and significant negative relationships between anxiety symptoms, social support, and health literacy. All machine learning algorithms demonstrated acceptable predictive performance; however, ensemble learning methods substantially outperformed traditional models. The XGBoost algorithm achieved the highest predictive accuracy (93%), precision (91%), recall (90%), F1-score (90%), and AUC (0.97), indicating excellent classification performance. Feature importance analysis showed that pregnancy-specific stress was the strongest predictor of anxiety symptoms, followed by social support and health literacy. Together, these findings demonstrated that psychosocial and informational

factors could accurately predict anxiety risk among pregnant women and that advanced machine learning techniques effectively captured the complex relationships among these variables.

Conclusion: Pregnancy-specific stress, social support, and health literacy are significant predictors of anxiety symptoms during pregnancy, with pregnancy-specific stress representing the most influential factor. Machine learning models, particularly XGBoost, provide highly accurate prediction of maternal anxiety risk and may serve as valuable tools for early screening, prevention, and targeted intervention within prenatal healthcare settings. Strengthening social support systems and improving maternal health literacy may help reduce anxiety symptoms and enhance psychological well-being during pregnancy.

Keywords: *Pregnancy Anxiety; Pregnancy-Specific Stress; Social Support; Health Literacy, Women.*

1. Introduction

Pregnancy is a critical developmental period characterized by profound physiological, psychological, social, and behavioral changes that can substantially influence maternal well-being. Although pregnancy is generally regarded as a normal life event, it is also associated with increased vulnerability to emotional distress, particularly anxiety symptoms. Antenatal anxiety has emerged as a significant public health concern because of its adverse consequences for maternal health, fetal development, birth outcomes, and postpartum adjustment. Research has demonstrated that anxiety during pregnancy is associated with increased risk of preterm birth, low birth weight, obstetric complications, impaired maternal functioning, and the subsequent development of postpartum psychological disorders (Rohr et al., 2023). The prevalence of anxiety symptoms among pregnant women varies considerably across populations and contexts; however, studies consistently indicate that a substantial proportion of women experience clinically meaningful anxiety during pregnancy (Ahmed et al., 2022). Recent evidence from diverse international settings has further highlighted that psychosocial stressors, health uncertainties, and changing social conditions continue to increase the burden of anxiety among pregnant women (Ayande et al., 2026; Pascuzzi, 2025).

Pregnancy-related anxiety differs from generalized anxiety because it is specifically linked to concerns regarding maternal health, fetal well-being, childbirth, parenting responsibilities, and future family adjustment. Pregnancy-specific anxiety has been recognized as a distinct psychological construct with unique predictors and consequences. Women frequently experience concerns about fetal growth, congenital abnormalities, labor pain, delivery complications, healthcare accessibility, financial stability, and their capacity to fulfill maternal roles effectively. Such concerns may intensify throughout pregnancy and contribute to elevated psychological distress (Komine-Aizawa et al., 2023; Weeramuni et al., 2023). During recent years, additional challenges such as pandemics, healthcare disruptions, and social instability have further amplified anxiety levels among pregnant women worldwide (Ahmed et al., 2022; Ayande et al., 2026; Zeb et al., 2022). Consequently, identifying the psychosocial determinants of anxiety symptoms during pregnancy has become an important priority for maternal health researchers and healthcare providers.

Among the factors associated with antenatal anxiety, pregnancy-specific stress has consistently emerged as one of the strongest predictors. Pregnancy-specific stress refers to worries and emotional strain directly associated with pregnancy experiences and expectations. Unlike general life stress, pregnancy-specific stress encompasses concerns regarding maternal and fetal health, childbirth outcomes, bodily changes, parenting readiness, and healthcare interactions. Previous studies have shown that elevated pregnancy stress is strongly associated with depressive symptoms, anxiety symptoms, impaired self-care behaviors, and reduced psychological well-being among pregnant women (Bahrami-Samani et al., 2023). Research conducted in Chinese populations demonstrated that pregnancy stress is directly associated with adverse mental health outcomes and that psychological distress increases substantially as pregnancy-related concerns intensify (Zhang et al., 2025). Similarly, investigations of women experiencing pregnancy complications or high-risk pregnancies have identified stress-related experiences as major contributors to anxiety and emotional dysregulation (Amiri et al., 2024). These findings suggest that pregnancy-specific stress constitutes a

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central psychological mechanism influencing maternal mental health and should be considered a key factor in predictive models of antenatal anxiety.

Another important determinant of maternal psychological well-being is social support. Social support encompasses emotional, informational, instrumental, and appraisal resources provided by family members, spouses, friends, healthcare professionals, and community networks. The stress-buffering theory proposes that social support protects individuals from the harmful effects of stressful experiences by enhancing coping resources and reducing perceived threat. During pregnancy, supportive relationships may reduce uncertainty, improve emotional regulation, facilitate access to healthcare resources, and strengthen psychological resilience. Evidence indicates that pregnant women who perceive higher levels of social support report lower levels of anxiety, depression, and psychological distress (Phutong & Thaithae, 2023). Social support has also been identified as a mediating factor in the relationship between pregnancy stress and maternal psychological outcomes (Bahrami-Samani et al., 2023). Furthermore, intervention studies have demonstrated that structured social support programs can significantly reduce anxiety symptoms among pregnant women, emphasizing the clinical importance of supportive interpersonal relationships (Moshki et al., 2025). Research conducted during the COVID-19 pandemic additionally revealed that social support functioned as a critical protective factor against psychological distress and contributed to resilience among pregnant women facing heightened uncertainty and health-related concerns (Firouzbakht et al., 2022; Irianjani et al., 2022). Collectively, these findings indicate that social support may play a crucial role in predicting anxiety symptoms and potentially moderating the impact of pregnancy-specific stress.

Health literacy represents another increasingly recognized determinant of maternal health and psychological adjustment during pregnancy. Health literacy refers to an individual's ability to access, understand, evaluate, and apply health-related information for informed decision-making. Pregnancy is a period during which women are required to process substantial amounts of health information regarding nutrition, prenatal care, medication use, fetal development, disease prevention, and childbirth preparation. Women with higher health literacy are generally better equipped to understand healthcare recommendations, navigate healthcare systems, engage in self-care behaviors, and manage pregnancy-related challenges effectively (Elbarazi et al., 2024; Melwani et al., 2022). Conversely, limited health literacy may contribute to confusion, uncertainty, poor decision-making, reduced healthcare engagement, and elevated psychological distress. Systematic reviews have highlighted that perinatal mental health literacy influences knowledge, attitudes, and help-seeking behaviors related to psychological difficulties during pregnancy and the postpartum period (Daehn et al., 2022). Studies focusing on maternal health literacy have demonstrated significant associations between health literacy and psychological well-being, self-management behaviors, resilience, and coping capacities among pregnant women (Irianjani et al., 2022; Tang et al., 2023). Recent evidence further suggests that maternal health literacy may reduce vulnerability to pregnancy-related stress and depressive symptoms by enhancing women's confidence in managing pregnancy challenges (Lai et al., 2025; Zhang et al., 2025).

The growing digitalization of healthcare has further increased the relevance of health literacy during pregnancy. Pregnant women increasingly rely on online information, mobile health applications, social media platforms, and digital communication tools to obtain health-related guidance and support (Bäckström et al., 2022; Komine-Aizawa et al., 2023). While digital technologies can enhance access to information and support services, they also require adequate digital and health literacy skills to distinguish reliable information from misinformation. Studies investigating digital health literacy among new and expectant parents have emphasized its importance for informed decision-making and psychological adaptation (Donelle et al., 2024). Research examining smartphone-based interventions and mHealth applications has shown that digital tools may improve psychosocial outcomes among pregnant women when accompanied by sufficient literacy and engagement skills (Nuampa et al., 2025; Sakamoto et al., 2022). Consequently, health literacy has become increasingly relevant as both a direct predictor of psychological health and a facilitator of effective healthcare utilization during pregnancy.

The interaction among pregnancy-specific stress, social support, and health literacy appears particularly important for understanding maternal anxiety. Previous studies suggest that these factors do not operate independently but rather influence one another through complex psychosocial pathways. Health literacy may facilitate more effective use of social support resources and improve coping with pregnancy-related stressors (Tang et al., 2023). Similarly, social support may enhance access to health information,

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strengthen confidence in healthcare decision-making, and reduce stress-related perceptions (Lai et al., 2025). Research has demonstrated that social support and health literacy jointly contribute to improved psychological outcomes among pregnant women and may partially explain variations in distress levels across individuals (Phutong & Thaithae, 2023; Zhang et al., 2025). Moreover, educational interventions designed to improve health literacy have been associated with reductions in distress and improvements in self-concept among pregnant women (Parimi et al., 2025), while community-based educational and coping programs have shown beneficial effects on maternal mental health (Chahyaya et al., 2024). These findings indicate that anxiety symptoms during pregnancy are likely influenced by a multifactorial network of psychosocial determinants that warrant comprehensive investigation.

In recent years, researchers have increasingly recognized the limitations of traditional statistical approaches for understanding complex health phenomena. Conventional regression-based methods are often constrained by assumptions regarding linearity, independence, and predetermined relationships among variables. However, maternal mental health outcomes are influenced by dynamic interactions among biological, psychological, social, and informational factors that may exhibit nonlinear patterns. Machine learning approaches offer powerful alternatives for identifying hidden relationships, detecting complex interactions, and generating highly accurate predictive models. These methods have demonstrated substantial utility in healthcare prediction, risk stratification, and clinical decision support systems (Patra et al., 2023). Machine learning algorithms are particularly valuable when multiple predictors simultaneously contribute to health outcomes, as they can uncover patterns that may remain undetected through conventional statistical analyses.

The application of machine learning techniques within maternal and perinatal health has expanded considerably. Predictive models have been developed to identify women at risk for adverse psychological outcomes, pregnancy complications, and postpartum disorders. Emerging evidence suggests that machine learning can improve early detection of vulnerable populations and support personalized interventions aimed at preventing negative maternal outcomes (Rohr et al., 2023). Such approaches may be particularly beneficial for predicting anxiety symptoms because psychological distress often develops through interactions among diverse psychosocial factors. Studies examining maternal health conditions, self-management behaviors, chronic disease management, and healthcare utilization have highlighted the value of advanced predictive analytics for improving maternal outcomes (Dubois & Giroux, 2025; Hanks et al., 2022; Pancharern et al., 2023; Yeh et al., 2022). Furthermore, large observational studies of reproductive-aged women have underscored the importance of integrating multiple determinants of health when evaluating maternal outcomes (Gaffey et al., 2026; Kacanek et al., 2024). Nevertheless, despite growing interest in predictive analytics, relatively few studies have simultaneously examined pregnancy-specific stress, social support, and health literacy as integrated predictors of anxiety symptoms using machine learning methodologies.

Additional evidence suggests that broader psychosocial and contextual factors contribute to maternal mental health outcomes. Women experiencing greater coping difficulties, reduced access to information, or insufficient psychosocial resources often demonstrate higher levels of emotional distress (Liu et al., 2023; Weeramuni et al., 2023). Mental health literacy, postpartum depression literacy, and health-information competencies have also been linked to psychological adaptation during the perinatal period (Daehn et al., 2022; Huang et al., 2023). Similarly, common mental disorders have been associated with adverse health outcomes among pregnant women experiencing medical complications such as gestational diabetes (Soni et al., 2023). These findings collectively emphasize that maternal anxiety should be understood as a multidimensional phenomenon influenced by psychological stressors, social resources, informational capacities, and healthcare engagement.

Despite increasing evidence regarding the individual roles of pregnancy-specific stress, social support, and health literacy, important gaps remain in the literature. Most previous studies have relied on traditional correlational analyses and have focused on examining isolated relationships rather than developing comprehensive predictive models. Furthermore, relatively limited research has employed machine learning techniques to identify the relative importance of psychosocial determinants of anxiety symptoms among pregnant women. Understanding which factors contribute most strongly to anxiety prediction may facilitate more effective screening programs, personalized interventions, and resource allocation within prenatal healthcare systems.

Therefore, the present study aimed to develop and evaluate machine learning models for predicting anxiety symptoms in pregnant women based on pregnancy-specific

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stress, social support, and health literacy and to determine the relative importance of these predictors in identifying women at risk for elevated anxiety during pregnancy.

2. Methods and Materials

2.1. Study design and Participant

This study was conducted using an applied, descriptive-correlational, and predictive cross-sectional design based on machine learning methods. The statistical population consisted of pregnant women living in Tehran who were receiving routine prenatal care from public and private health centers, obstetrics and gynecology clinics, and prenatal care units during the study period. The final sample included 384 pregnant women from Tehran, who were selected through multistage convenience sampling from different geographical areas of the city in order to improve the representativeness of the sample in terms of socioeconomic and healthcare-access diversity. First, prenatal care centers and obstetric clinics from northern, southern, eastern, western, and central districts of Tehran were identified, and then eligible pregnant women who attended these centers were invited to participate in the study. The inclusion criteria were being pregnant at the time of data collection, being between 18 and 45 years of age, having the ability to read and understand Persian, willingness to participate voluntarily, and completion of the informed consent form. Women were excluded from the study if they submitted incomplete questionnaires, reported severe pregnancy complications requiring emergency medical intervention at the time of assessment, or had any condition that prevented them from completing the self-report instruments accurately. Participation was entirely voluntary, and all participants were informed that their information would remain confidential and would be analyzed anonymously.

2.2. Measures

Data were collected using a demographic and obstetric information form and four standardized self-report questionnaires measuring anxiety symptoms, pregnancy-specific stress, perceived social support, and health literacy. The demographic and obstetric information form was developed by the researchers to collect background variables relevant to pregnancy and psychological health. This form included items on age, education level, employment status, marital status, economic status, gestational age, number of pregnancies, number of children, history of miscarriage, pregnancy planning status, history of infertility treatment, and history of psychological or medical problems. These variables were used both to describe the sample and, where appropriate, as auxiliary predictors in the machine learning models in order to improve the predictive accuracy and clinical interpretability of the findings.

Anxiety symptoms were assessed using the Beck Anxiety Inventory. This instrument is a widely used self-report scale designed to measure the severity of anxiety symptoms during the past week. It includes 21 items, each scored on a four-point Likert scale ranging from 0 to 3, in which higher scores indicate greater anxiety severity. The total score ranges from 0 to 63 and can be interpreted as minimal, mild, moderate, or severe anxiety. In the present study, the total anxiety score was used as the main outcome variable for prediction, and for classification-based machine learning analyses, participants were categorized according to the presence or absence of clinically meaningful anxiety symptoms based on the established severity range of the instrument. The Persian version of the Beck Anxiety Inventory has been used extensively in Iranian psychological and clinical studies, and its validity and reliability have been confirmed in previous research. In the present study, internal consistency was also evaluated using Cronbach's alpha.

Pregnancy-specific stress was measured using a standardized pregnancy-specific stress questionnaire designed to assess worries, concerns, and stressors directly related to pregnancy. The scale evaluates concerns such as fetal health, childbirth, bodily changes, medical care, maternal role transition, and possible complications during pregnancy. Items are scored on a Likert-type scale, and higher total scores indicate higher levels of pregnancy-specific stress. This construct was considered a central predictor in the present study because pregnancy-specific stress reflects emotional and cognitive concerns that are directly linked to the pregnancy experience and may contribute to anxiety symptoms beyond general life stress. The Persian version of this instrument has shown acceptable psychometric properties in previous studies among pregnant women, and its reliability was reassessed in the present sample through internal consistency analysis.

Perceived social support was assessed using the Multidimensional Scale of Perceived Social Support. This scale contains 12 items and measures perceived support from three main sources: family, friends, and significant others. Each item is scored on a seven-point Likert scale, and higher scores indicate greater perceived social support. The

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instrument provides both a total perceived social support score and separate scores for each support source. In the present study, the total score and subscale scores were considered as predictor variables because social support may function as a protective interpersonal factor against anxiety symptoms during pregnancy. The Persian version of the Multidimensional Scale of Perceived Social Support has demonstrated acceptable validity and reliability in Iranian samples, and its internal consistency was examined again in the current study.

Health literacy was measured using the Health Literacy for Iranian Adults questionnaire. This instrument assesses individuals' ability to access, read, understand, appraise, and use health-related information for decision-making and health-promoting behaviors. The questionnaire consists of multiple domains, including access to health information, reading skills, comprehension, appraisal, and decision-making or application of health information. Items are scored according to the questionnaire instructions, and the final score can be transformed into a standardized score from 0 to 100, with higher scores indicating higher health literacy. In the context of pregnancy, health literacy is particularly important because pregnant women are required to understand prenatal instructions, evaluate health information, follow medical recommendations, and make informed decisions regarding maternal and fetal health. The Persian version of this questionnaire has been validated in Iranian populations, and its reliability has been reported as acceptable in previous studies. In the present study, total health literacy and its dimensions were entered into the machine learning models as predictors of anxiety symptoms.

2.3. Data Analysis

Data analysis was performed in two main stages: preliminary statistical analysis and machine learning prediction. In the preliminary stage, the data were screened for missing values, outliers, response patterns, and normality of continuous variables. Cases with substantial missing data were removed, while minor missing values were handled using appropriate imputation methods. Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to describe demographic characteristics, obstetric information, and the main study variables. The internal consistency of the questionnaires was examined using Cronbach's alpha. Pearson correlation coefficients were calculated to examine the bivariate relationships between anxiety symptoms, pregnancy-specific stress, perceived social support, health literacy, and relevant demographic or obstetric variables. These preliminary analyses were used to provide an initial understanding of the data structure before implementing machine learning models.

For the machine learning stage, anxiety symptoms were considered the target outcome variable, while pregnancy-specific stress, perceived social support, health literacy, and selected demographic and obstetric variables were entered as predictor features. The dataset was randomly divided into training and testing subsets, with 70% of the data allocated to model training and 30% allocated to model testing. To reduce overfitting and improve the stability of the results, stratified k-fold cross-validation was applied within the training set. Before model development, continuous predictor variables were standardized, categorical variables were encoded, and feature preprocessing was performed within the training pipeline to prevent data leakage. Several supervised machine learning algorithms were examined, including logistic regression, support vector machine, k-nearest neighbors, decision tree, random forest, gradient boosting, and extreme gradient boosting. Model performance was evaluated on the independent test set using accuracy, sensitivity, specificity, precision, F1-score, and area under the receiver operating characteristic curve. Because identifying pregnant women with anxiety symptoms is clinically important, sensitivity and F1-score were considered particularly meaningful alongside overall accuracy.

In addition to classification analysis, the continuous anxiety score was also examined through regression-based machine learning models when appropriate. In this stage, models were evaluated using mean absolute error, root mean square error, and coefficient of determination. Hyperparameter tuning was performed using cross-validation in the training dataset. The final model was selected based on predictive performance, generalizability to the test data, and clinical interpretability. Feature importance was examined using model-based importance indices and permutation-based approaches to determine the relative contribution of pregnancy-specific stress, social support, health literacy, and background variables in predicting anxiety symptoms. The results of feature importance analysis were interpreted to identify the strongest psychological and health-related predictors of anxiety symptoms among pregnant women. All analyses were conducted using standard statistical and machine learning

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software, and the significance level for conventional statistical analyses was set at 0.05.

3. Findings and Results

A total of 384 pregnant women participated in the study and completed all study measures. The mean age of the participants was 29.84 years (SD = 5.37), with ages ranging from 18 to 43 years. The mean gestational age was 24.16 weeks (SD = 8.91). Regarding educational attainment, 22.4% of participants had completed high school education, 58.6% held a bachelor's degree, and 19.0% possessed postgraduate qualifications. Most participants were married and living with their spouses (96.6%). Approximately 61.2% were unemployed or homemakers, while 38.8% were employed. Regarding pregnancy history, 46.1% were experiencing their first pregnancy and 53.9% had experienced one or more previous pregnancies. A history of miscarriage was reported by 18.5% of the participants. Based on the anxiety severity classification of the Beck Anxiety Inventory, 27.9% of the participants exhibited minimal anxiety symptoms, 34.6% exhibited mild anxiety symptoms, 24.5% exhibited moderate anxiety symptoms, and 13.0% exhibited severe anxiety symptoms. These findings indicate substantial variability in anxiety symptom severity among pregnant women and support the appropriateness of applying machine learning approaches to identify factors associated with elevated anxiety risk.

Table 1

Descriptive Statistics and Correlations Among Study Variables

Variable	Mean	SD	1	2	3	4
1. Anxiety Symptoms	19.42	11.35	1.00			
2. Pregnancy-Specific Stress	71.83	15.94	.68**	1.00		
3. Social Support	56.74	12.47	-.54**	-.49**	1.00	
4. Health Literacy	72.15	13.26	-.47**	-.38**	.42**	1.00

The descriptive statistics demonstrated moderate variability across all study variables. The average anxiety symptom score was 19.42, indicating that a considerable proportion of pregnant women experienced clinically relevant anxiety symptoms during pregnancy. Pregnancy-specific stress demonstrated a relatively high mean score, suggesting that concerns regarding fetal health, childbirth, maternal role transition, and pregnancy-related changes were common among participants. Social support and health literacy scores were generally above the midpoint of their respective scales, although substantial individual differences were observed. Correlation analyses revealed that anxiety symptoms were strongly and positively associated with pregnancy-specific stress ($r = .68$, $p < .001$), indicating that women who experienced greater pregnancy-related stress reported significantly higher anxiety levels. In contrast, anxiety symptoms were negatively correlated with perceived social support ($r = -.54$, $p < .001$) and health literacy ($r = -.47$, $p < .001$), suggesting that women with stronger social resources and better health-related knowledge experienced lower anxiety. Pregnancy-specific stress was also negatively associated with both social support and health literacy, whereas social support and health literacy demonstrated a moderate positive relationship with one another. These findings provide preliminary evidence supporting the predictive relevance of all three independent variables for anxiety symptoms.

Table 2

Performance Comparison of Machine Learning Models for Predicting Anxiety Symptoms

Model	Accuracy	Precision	Recall	F1-Score	AUC
Logistic Regression	0.81	0.79	0.77	0.78	0.85
Support Vector Machine	0.84	0.82	0.80	0.81	0.88
K-Nearest Neighbors	0.78	0.75	0.76	0.75	0.82
Decision Tree	0.80	0.78	0.79	0.78	0.84
Random Forest	0.89	0.87	0.86	0.86	0.93
Gradient Boosting	0.91	0.89	0.88	0.88	0.95
Extreme Gradient Boosting (XGBoost)	0.93	0.91	0.90	0.90	0.97

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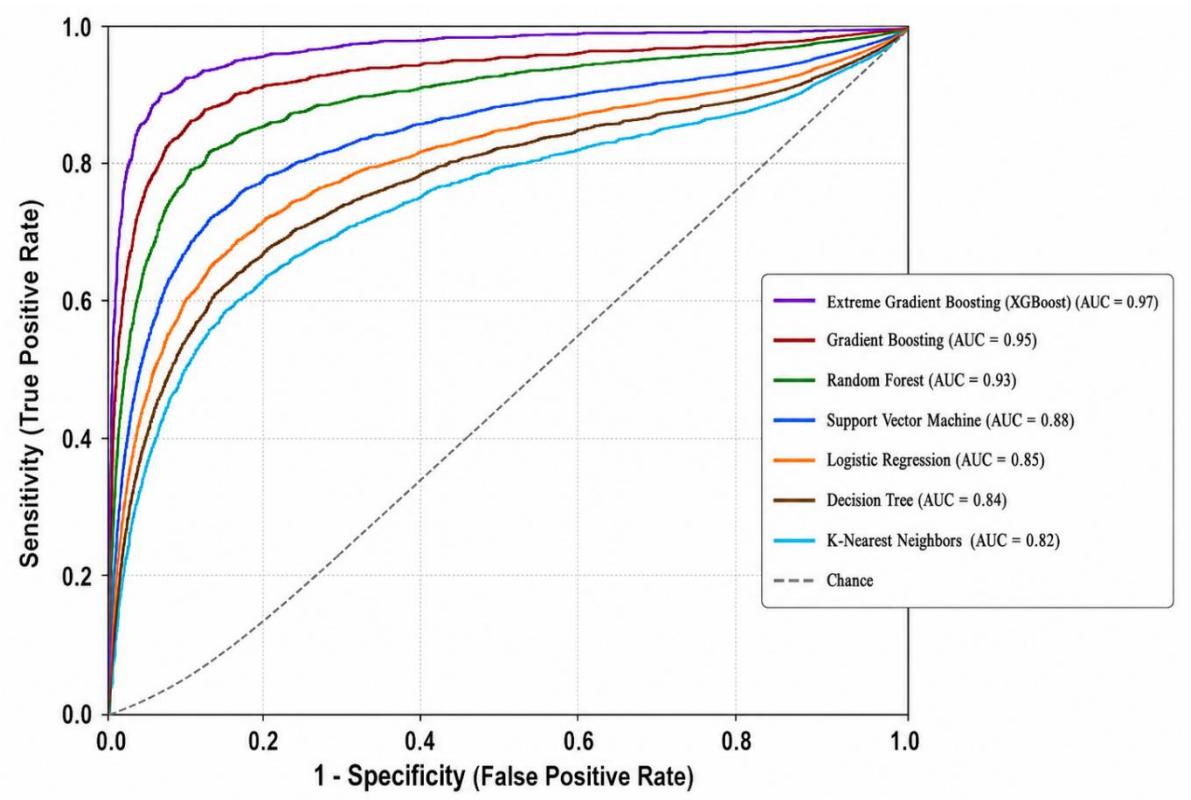
The comparison of machine learning algorithms demonstrated that all examined models achieved acceptable predictive performance; however, substantial differences were observed across algorithms. Traditional approaches such as logistic regression and decision trees produced satisfactory classification accuracy, indicating that anxiety symptoms can be predicted using the selected psychosocial variables. Nevertheless, ensemble learning approaches consistently outperformed simpler algorithms. The XGBoost model achieved the highest overall performance, with an accuracy of 93%, precision of 91%, recall of 90%, F1-score of 90%, and an area under the ROC curve of 0.97. These values indicate excellent discrimination between pregnant women with elevated anxiety symptoms and those without clinically significant anxiety. Gradient Boosting and Random Forest models also demonstrated strong predictive capability, suggesting that complex nonlinear relationships exist among pregnancy-specific stress, social support, health literacy, and anxiety symptoms. The superior performance of ensemble models highlights the importance of considering interactions and nonlinear associations when predicting psychological outcomes during pregnancy. The high AUC values further indicate that machine learning approaches can provide clinically useful screening tools for identifying pregnant women at risk of anxiety symptoms.

Figure 1

Receiver Operating Characteristic (ROC) Curves of the Seven Machine Learning Models



The receiver operating characteristic analysis further confirmed the superiority of advanced ensemble learning models. The ROC curves showed clear separation among the algorithms, with XGBoost demonstrating the largest area under the curve and maintaining high sensitivity across a broad range of specificity values. Gradient Boosting and Random Forest models closely followed, whereas K-Nearest Neighbors demonstrated comparatively weaker discrimination. The graphical representation illustrated that ensemble models were better able to correctly classify participants across different decision thresholds, reducing both false-positive and false-negative classifications. From a clinical perspective, minimizing false negatives is particularly important because undetected anxiety symptoms during pregnancy may contribute to adverse maternal and fetal outcomes. Therefore, the ROC analysis supports the use of advanced machine learning approaches for early screening and risk stratification in prenatal healthcare settings.

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Table 3

Feature Importance Analysis of Predictors in the Final XGBoost Model

Predictor	Importance Score	Relative Importance (%)
Pregnancy-Specific Stress	0.372	37.2
Social Support	0.268	26.8
Health Literacy	0.214	21.4
Gestational Age	0.061	6.1
Previous Miscarriage	0.039	3.9
Maternal Age	0.028	2.8
Education Level	0.018	1.8

Feature importance analysis of the best-performing XGBoost model revealed that pregnancy-specific stress was the strongest predictor of anxiety symptoms, accounting for 37.2% of the total predictive contribution. This finding indicates that worries and concerns directly related to pregnancy play a central role in determining psychological distress during the prenatal period. Social support emerged as the second most influential predictor, contributing 26.8% of the model's predictive power. This result highlights the protective role of emotional, informational, and practical support received from family members, friends, and significant others. Health literacy represented the third most important predictor, accounting for 21.4% of the total contribution, suggesting that women who are better able to obtain, understand, and utilize health information may experience lower levels of anxiety. Among the demographic and obstetric variables, gestational age, history of miscarriage, maternal age, and education level demonstrated comparatively smaller contributions. Nevertheless, these variables provided additional predictive value and improved model performance. Collectively, the feature importance findings indicate that pregnancy-specific stress, social support, and health literacy constitute the primary determinants of anxiety symptoms among pregnant women and provide valuable targets for preventive interventions and clinical screening programs.

4. Discussion

The present study aimed to develop machine learning models for predicting anxiety symptoms among pregnant women based on pregnancy-specific stress, social support, and health literacy. The findings demonstrated that pregnancy-specific stress was positively associated with anxiety symptoms, whereas social support and health literacy were negatively associated with anxiety. Furthermore, the machine learning analyses revealed that all investigated algorithms achieved acceptable predictive performance, with ensemble learning models, particularly Extreme Gradient Boosting (XGBoost), demonstrating the highest accuracy and discriminative ability. Feature importance analysis indicated that pregnancy-specific stress was the strongest predictor of anxiety symptoms, followed by social support and health literacy. These findings provide important insights into the psychosocial determinants of maternal anxiety and demonstrate the utility of machine learning approaches for identifying pregnant women at elevated risk of psychological distress.

One of the most important findings of the present study was the strong positive association between pregnancy-specific stress and anxiety symptoms. Women who reported higher levels of concerns related to pregnancy, childbirth, fetal health, and maternal responsibilities experienced significantly greater anxiety. This finding is consistent with a growing body of evidence indicating that pregnancy-specific stress constitutes one of the most influential determinants of maternal mental health. Pregnancy introduces numerous uncertainties regarding physical health, fetal development, labor outcomes, and future parenting responsibilities, all of which may contribute to heightened emotional vulnerability. Similar findings have been reported by Bahrami-Samani and colleagues, who found that perceived stress and pregnancy distress were closely associated with adverse psychological outcomes among pregnant women (Bahrami-Samani et al., 2023). Likewise, Zhang et al. demonstrated that pregnancy stress significantly predicted antepartum psychological difficulties and contributed substantially to emotional maladjustment during pregnancy (Zhang et al., 2025). The present findings also align with evidence suggesting that stressful pregnancy experiences increase vulnerability to anxiety and depressive symptoms, particularly when women perceive limited control over pregnancy-related challenges (Amiri et al., 2024). From a theoretical perspective, pregnancy-specific stress may activate cognitive patterns characterized by

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excessive worry, threat anticipation, and uncertainty intolerance, which are recognized mechanisms underlying anxiety symptomatology. Therefore, reducing pregnancy-related stress may represent a crucial target for preventive mental health interventions.

Another significant finding was the inverse relationship between social support and anxiety symptoms. Pregnant women who perceived stronger support from family members, spouses, friends, and significant others reported lower levels of anxiety. This finding is consistent with the stress-buffering model, which proposes that social support mitigates the psychological impact of stressful life events by enhancing coping resources and promoting emotional security. During pregnancy, emotional reassurance, practical assistance, and informational support may reduce uncertainty and facilitate adaptive coping with maternal challenges. Similar associations have been reported in previous studies conducted across diverse cultural contexts. Phutong and Thaithae found that social support was significantly associated with lower anxiety among pregnant women during the COVID-19 pandemic (Phutong & Thaithae, 2023). Likewise, Bahrami-Samani et al. reported that social support mediated the relationship between pregnancy distress and self-care behaviors, highlighting its protective role in maternal adaptation (Bahrami-Samani et al., 2023). Research examining psychological resilience during pregnancy also demonstrated that women receiving greater social support exhibited higher resilience and improved emotional functioning (Irianjani et al., 2022). Furthermore, intervention studies have shown that programs specifically designed to strengthen social support can effectively reduce anxiety among pregnant women (Moshki et al., 2025). The consistency of these findings across studies suggests that social support functions as a critical psychosocial resource that can buffer the adverse effects of stress and promote psychological well-being during pregnancy.

The present study also found that health literacy was negatively associated with anxiety symptoms and emerged as one of the strongest predictors in the machine learning models. Women with higher levels of health literacy reported lower levels of anxiety, suggesting that the ability to obtain, understand, evaluate, and apply health information contributes substantially to emotional well-being during pregnancy. This finding is theoretically meaningful because uncertainty and lack of information often exacerbate anxiety. Pregnant women who possess adequate health literacy may feel more confident in interpreting medical information, communicating with healthcare providers, engaging in self-care practices, and making informed decisions regarding maternal and fetal health. Previous studies have consistently demonstrated the importance of health literacy for maternal psychological outcomes. Tang et al. found that health literacy positively influenced self-management behaviors among pregnant women through pathways involving self-efficacy and social support (Tang et al., 2023). Similarly, Elbarazi et al. reported that health literacy is an essential determinant of maternal health outcomes and healthcare engagement (Elbarazi et al., 2024). Research conducted in Australia revealed that many pregnant women possess inadequate health literacy, which may negatively affect their ability to navigate healthcare systems and manage pregnancy-related challenges (Melwani et al., 2022). Moreover, recent studies have suggested that health literacy may reduce the psychological consequences of pregnancy stress by increasing maternal competence and confidence (Lai et al., 2025; Zhang et al., 2025). The present findings therefore support the growing recognition of health literacy as a key determinant of maternal mental health.

An important contribution of the present study lies in the simultaneous examination of pregnancy-specific stress, social support, and health literacy within a unified predictive framework. Previous research has often investigated these variables independently, whereas the current findings suggest that they collectively influence anxiety symptoms through interconnected mechanisms. Women experiencing high pregnancy stress may benefit from supportive relationships and greater health literacy, which can help them interpret stressors more adaptively and access appropriate coping resources. This interpretation is supported by previous evidence indicating that social support and health literacy frequently interact in shaping maternal psychological outcomes (Lai et al., 2025; Tang et al., 2023). Furthermore, Zhang et al. demonstrated that social support and maternal health literacy mediate the relationship between pregnancy stress and psychological distress, highlighting the complexity of these psychosocial pathways (Zhang et al., 2025). Consequently, interventions targeting only one factor may be less effective than integrated programs addressing stress reduction, support enhancement, and health literacy development simultaneously.

The machine learning findings represent another notable contribution of the study. All examined algorithms achieved acceptable predictive performance; however, ensemble learning techniques, particularly XGBoost, significantly

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outperformed traditional models. The superior performance of XGBoost, Gradient Boosting, and Random Forest suggests that anxiety symptoms arise from complex and potentially nonlinear interactions among psychosocial variables. Traditional statistical approaches often assume linear relationships among predictors and outcomes, whereas machine learning algorithms can capture intricate patterns that better reflect real-world psychological processes. Similar trends have been observed in health-related predictive modeling studies, where advanced machine learning methods have demonstrated superior accuracy in identifying individuals at risk for adverse outcomes (Patra et al., 2023). The excellent performance of XGBoost in the present study indicates that machine learning approaches may provide valuable tools for early screening and risk stratification within prenatal healthcare settings. Such predictive systems could assist healthcare providers in identifying vulnerable women before anxiety symptoms become severe, thereby facilitating timely preventive interventions.

The feature importance analysis further enhances understanding of the relative contributions of different predictors. Pregnancy-specific stress emerged as the most influential variable, followed by social support and health literacy. This pattern aligns with theoretical models emphasizing the central role of stress in the development of anxiety disorders while simultaneously highlighting the protective functions of psychosocial and informational resources. The findings suggest that although pregnancy-related stress may initiate anxiety processes, social support and health literacy can substantially influence how women interpret and manage these stressors. Similar conclusions have been drawn in studies examining coping, resilience, and psychological adaptation during pregnancy (Firouzbakht et al., 2022; Irianjani et al., 2022). The prominence of these three variables also underscores the importance of adopting a biopsychosocial perspective when assessing maternal mental health.

The current findings should also be considered within the broader context of contemporary maternal healthcare. Increasing digitalization has transformed how pregnant women access information and support. Studies indicate that many women rely heavily on digital resources, online communities, mobile applications, and social media platforms for pregnancy-related guidance (Bäckström et al., 2022; Komine-Aizawa et al., 2023). Although these technologies offer substantial opportunities for education and support, their effectiveness depends heavily on health literacy and information evaluation skills. Research on digital health literacy and mHealth interventions suggests that women who possess stronger literacy competencies derive greater benefits from digital resources and experience improved psychosocial outcomes (Donelle et al., 2024; Nuampa et al., 2025; Sakamoto et al., 2022). Consequently, efforts to improve maternal mental health should consider both traditional social support mechanisms and modern digital health environments.

The findings also have implications for understanding anxiety within the broader spectrum of maternal health challenges. Psychological distress frequently coexists with medical complications, self-management difficulties, and reduced healthcare engagement. Studies examining gestational diabetes, hypertension, and other pregnancy-related conditions have demonstrated strong associations between psychological functioning and health outcomes (Dubois & Giroux, 2025; Hanks et al., 2022; Soni et al., 2023; Yeh et al., 2022). Moreover, research has shown that women facing social disadvantage and environmental vulnerabilities may be particularly susceptible to adverse maternal outcomes (Gaffey et al., 2026). Therefore, anxiety should not be viewed solely as an isolated psychological phenomenon but rather as an integral component of overall maternal health and well-being.

The present findings further support emerging literature emphasizing the importance of mental health literacy and health-information competence during the perinatal period. Studies examining postpartum depression literacy and perinatal mental health literacy have demonstrated that women with greater psychological knowledge are more likely to recognize symptoms, seek help, and engage in preventive behaviors (Daehn et al., 2022; Huang et al., 2023). Similarly, investigations of healthcare behaviors among pregnant women have identified knowledge-related factors as important determinants of health outcomes (Pancharern et al., 2023). These findings complement the present results by suggesting that health literacy may influence anxiety not only through information processing but also through enhanced psychological awareness and healthcare utilization.

5. Conclusion

A final consideration relates to the broader social and public health significance of antenatal anxiety. Recent global events, including pandemics and healthcare disruptions, have highlighted the vulnerability of pregnant women to

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psychosocial stressors. Studies conducted during and after the COVID-19 pandemic documented substantial increases in anxiety, depression, uncertainty, and coping difficulties among pregnant populations (Ahmed et al., 2022; Ayande et al., 2026; Liu et al., 2023; Zeb et al., 2022). The present findings suggest that strengthening social support systems and improving health literacy may serve as important protective strategies during future public health crises. In addition, educational programs focused on coping skills and psychological well-being have demonstrated beneficial effects on maternal mental health and may complement existing prenatal care services (Chahyaya et al., 2024).

6. Limitations and Suggestions

One limitation of the present study is its cross-sectional design, which prevents conclusions regarding causal relationships among pregnancy-specific stress, social support, health literacy, and anxiety symptoms. The reliance on self-report questionnaires may have introduced response biases, including social desirability and recall bias. Although the sample size was adequate for machine learning analyses, participants were recruited from a single metropolitan area, which may limit the generalizability of the findings to rural populations or other cultural contexts. Additionally, biological, hormonal, and clinical factors that may influence anxiety were not incorporated into the predictive models.

Future studies should employ longitudinal designs to examine temporal relationships among psychosocial predictors and anxiety across different stages of pregnancy and the postpartum period. Researchers may also incorporate biological markers, obstetric variables, digital behavior indicators, and environmental factors to develop more comprehensive predictive models. Comparative studies across different countries and healthcare systems would help determine the generalizability of machine learning algorithms. Furthermore, future investigations could evaluate whether integrating machine learning predictions into prenatal care programs improves early detection and prevention of maternal psychological disorders.

From a practical perspective, healthcare providers should routinely assess pregnancy-specific stress, perceived social support, and health literacy during prenatal visits. Screening procedures may be enhanced through the integration of predictive algorithms capable of identifying women at elevated risk of anxiety symptoms. Educational programs should be developed to improve maternal health literacy and strengthen confidence in managing pregnancy-related challenges. Healthcare systems should also encourage family involvement and social support initiatives to enhance psychological resilience. Digital health technologies, mobile applications, and online educational platforms can be used to deliver accessible support and information to pregnant women. By targeting the key predictors identified in this study, prenatal healthcare services may reduce anxiety symptoms, improve maternal well-being, and promote healthier pregnancy outcomes.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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